The Journal of Mathematics and Science:

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Volume 4, Number 1 Spring 2001

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The Massachusetts Collaborative for Excellence in Teacher Preparation

Coordinating Editors
for this Special Issue
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AN INTRODUCTION TO STEMTEC AND "PATHWAYS TO CHANGE"

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STEMTEC is the Massachusetts Collaborative for Excellence in Teacher Preparation. The first step in preparing future teachers is to have them experience effective teaching in college science and mathematics courses. The Science, Technology, Engineering, and Mathematics Teacher Education Collaborative (STEMTEC) summer institutes familiarized 150 faculty members with a variety of teaching strategies recommended in the National Science Teaching Standards. These faculty incorporated the techniques into one or more of their courses during subsequent academic years, and many of them reported on their progress during a research conference, "Pathways to Change," which STEMTEC sponsored in the summer of 2000. Eleven papers, based on these conference reports, are included in this volume.

STEMTEC: A Brief Overview

STEMTEC (Science, Technology, Engineering, and Mathematics Teacher Education Collaborative) is the Massachusetts Collaborative for Excellence in Teacher Preparation (CETP), funded by the National Science Foundation in 1997. During a seven-year period starting in 1992, the Division of Undergraduate Education (DUE) established twenty CETP sites around the nation with the purpose of drawing more and better qualified undergraduates into K-12 science and mathematics teaching. Although each CETP program has this common goal, the sites differ in emphasis and approach.

STEMTEC initiated a comprehensive effort to improve the quality of teaching by science and mathematics faculty as a stimulus for undergraduates to consider careers in K-12 teaching. We reasoned that students would become more interested in these subjects, and also in teaching, if their own college professors were aware of good pedagogical practices, especially those recommended by the National Science Teaching Standards [1]. Numerous studies published between 1986 and 1997 show that good students are leaving science, mathematics, and engineering majors because of poor teaching, especially in introductory courses [2,3]. Teaching techniques in these courses typically emphasize memorization, coverage, and competition, whereas the recommendations for effective teaching and learning call for greater emphasis on the process of science, inquiry, and cooperative learning [1,4,5,6]. Many college professors were unaware of these recommendations, or of the research upon which they are based.

As a group, university science professors are notoriously resistant to changing how and what they teach. In our STEMTEC video, *How Change Happens: Breaking the Teach As You Were Taught Cycle in Science and Math*, Dean Linda Slakey of the University of Massachusetts (UMass) Amherst says that getting university science and mathematics faculty to focus on teaching improvement is often " ... like herding cats. We hire them because they are good at what they do..." referring primarily to their ability to do research in their respective academic disciplines. In addition, most college faculty have had little or no training in pedagogy and theories of cognition or in the principles and methods of evaluation. So we designed a very ambitious program of summer institutes, follow-up sessions, and implementation, to familiarize college faculty with these aspects of teaching.

The faculty development aspect of STEMTEC has involved nearly 25% of the college science and mathematics faculty in the original eight-college collaborative (Amherst College, Greenfield Community College, Hampshire College, Holyoke Community College, Mount Holyoke College, Smith College, Springfield Technical Community College, and the University of Massachusetts Amherst). Over three years, we ran summer institutes for eighty faculty members in biology, chemistry, geology, physics, and mathematics who contracted to redesign at least one of their courses using the principles learned at the institute. The faculty were organized into teams by discipline to investigate common themes that could be pursued in redesigning undergraduate courses. Each team included two K-12 teachers who served as pedagogical experts in assisting the college faculty in their task. The collaborative expanded in 1999 and 2000 to include faculty from other colleges throughout Massachusetts where teacher training was emphasized. Participation from fifteen additional colleges increased the number of faculty who have taken our workshops to 150.

"Pathways to Change" is an important outcome of these STEMTEC institutes. In place of a follow-up institute for our original participants in the summer of 2000, we conceived the idea of a model research conference, where faculty members could showcase their accomplishments under the STEMTEC program. These include the redesign of undergraduate courses, new assessment strategies, and mechanisms for bringing students into K-12 classrooms and other teaching settings. This conference featured STEMTEC college and K-12 faculty from a wide range of disciplines and institutions who gave presentations and were discussion leaders. Several of the presenters prepared manuscripts based on their contribution, and these constitute the proceedings of "Pathways to Change," the first part of this journal volume.

STEMTEC Course Redesign and Recommended Pedagogical Practices

The authors in this collection of papers refer to particular pedagogical practices advocated during the STEMTEC institutes, such as Problem Based Learning (PBL), alternative assessment (e.g., "the pyramid exam"), and K-16 collaborations. To put these references in context, we describe relevant aspects of the summer program.

During the summer institutes, we invited session leaders who were well known for their ability to introduce college faculty to current research in teaching and learning, and demonstrate practical applications to the college classroom. These facilitators focused on several components of student-active methods that are discussed in the articles that follow. Some terms and concepts that the authors mention are explained more fully below.

- Cooperative Learning is characterized by both group and individual accountability. Group members are responsible for their own learning and that of the entire group. Groups are small (typically 3-5), teamwork skills are emphasized, and members share group roles with frequent processing of group effectiveness.

  <u>Positive Interdependence</u> – students work together to accomplish a task in which success depends on participation by each person.

  <u>Informal Groups</u> – these are typically used to break up a lecture and in large classes; students are not assigned specific roles and structure is minimal; can be ad hoc, as in "think-pair-share."

  <u>Formal Groups</u> – students assume specific roles (e.g., facilitator, skeptic, recorder, reporter).

  <u>Problem Based Learning (PBL)</u> – PBL was developed by medical schools in the 1950's and has been adapted for a variety of teaching situations. Students are given a problem or a puzzle "cold" (such as the symptoms of an ill patient) and work together in formal groups to discuss what is known, develop possible hypotheses about the problem, and work together to find and synthesize information needed to solve it.

- Alternative Assessment refers to modifications or replacements for the traditional, in-class individual exam as a way of measuring student performance.

  <u>Pyramid Exam</u> – This exam was developed at Smith College [7] in order for students in calculus classes to work both alone and in cooperative groups on realistic, very

challenging questions for a test. The process builds on itself (is a "pyramid") and allows students to work alone and in groups on the same test over several days. STEMTEC faculty have modified the exam for students in large classes as a one-hour "two step" exam. In this modification, students take the test alone and hand it in; they then work in informal groups with other students and retake the test either as a group or individually. Other variants include giving students a chance to reason through their incorrect answers after the exam and to explain why their answers were wrong (and the correct answer was right).

- Evaluation is used primarily to refer to feedback from students on the impact of teaching methods or their learning experiences.

  Formative evaluation – looks at the course (or project) all along the way and its purpose is to give ongoing diagnosis and feedback so that professors can change their teaching if needed. It is diagnostic, non-judgmental, private, often anonymous, and specific [8].

  Summative evaluation – this is the familiar end-of-semester course evaluation, usually done in a multiple-choice format.

- Instructional technology refers primarily to computer-based methods to enhance learning and the classroom environment. This includes presentation software, web-based instructional tools and electronic classroom communication systems.

  Classtalk – this is a classroom technology that allows students to electronically register answers to questions posed in class and immediately displays the classes' responses on histograms displayed in front of the classroom. *Classtalk* gives faculty and students quick feedback to questions designed to uncover fundamental misconceptions and lack of understanding. A wireless version of this technology, called the Personal Response System (PRS) is now being introduced into some courses.

  OWL – On-line Web-based Learning is a way that students can complete quizzes and homework assignments interactively. The usual application is to have students complete a series of multiple-choice questions about a topic in the reading or discussed in class. OWL is set up so that if a student picks the wrong answer, the question is re-phrased, with new choices. The design helps ensure that students answering correctly will understand the reasoning behind their answer.

- Teaching experiences involve making the student an instructor on some level. The preferred mode is to have students teach in K-12 classroom settings in order to have a real taste of what the profession is all about.

The "Pathways to Change" Papers

The eleven articles that follow were all presented as oral contributions during our first "Pathways to Change" conference in June 2000. They are grouped by discipline, so that readers can find teaching and learning accomplishments aligned with their own areas more easily. Within each discipline, the papers are grouped alphabetically by senior author. Although most of the articles discuss specific courses and the changes in teaching and learning that have occurred within them, a few deal with more general methods that are helpful in improving science and mathematics education or the preparation of prospective teachers. The following table will help in finding the pedagogical practices highlighted in the articles:

Discipline	Author	Cooperative Learning	Alternative Assessment	Evaluation	Instructional Technology	Teaching Experiences
Biology	Bruno	PBL				
Biology	Kunkel	Projects	Writing		Web	
Biology	Prattis					K-12
Biology	Rapoport			Formative, Summative		K-12
Chemistry	Tyson	Groups	Pyramid Exams Writing	Summative		K-12
Engineering	Ganz	Groups Projects	Pyramid Quizzes	Summative	Interactive Web	
Mathematics	Connors	Groups	Projects		Presentation	
Mathematics	Peelle	Groups	Various		Computers	
Mathematics	Eisenberg	Groups	Pyramid Exams	Summative	*Mathematica*	
Physics	Mullin	Groups	Pyramid Exams Projects, Essays		PRS Website	Student TA
Physics	Rabin	Groups	Pyramid Exams	Summative	*Classtalk* OWL	

The Impact of STEMTEC on the Teaching of Science and Mathematics

These articles represent a small number of faculty members who changed their teaching as a result of the STEMTEC program. Many more were evaluated through case studies, student surveys, faculty surveys, and classroom observations. Detailed description of the substantial evaluation findings is beyond the scope of this introduction, but we include some highlights.

Case studies of several STEMTEC courses document numerous improvements in courses taught by faculty who had taken STEMTEC workshops [9]. These changes include increased class attendance, interest in the subject matter, greater confidence in their ability to be successful in technical courses, better understanding of the process of science, and increased interest in K-12 teaching. Student survey data show that students still spent a significant amount of time listening and taking notes in STEMTEC courses, but interaction among the students, and between the class and the instructor, increased noticeably. The following activities were also reported as taking place "about half the time": 1) working in small groups or pairs; 2) solving problems or answering open-ended questions during class; and, 3) giving formative feedback to the instructor. STEMTEC students were more likely to be interested in taking more science and math courses, they liked the subject matter more, and they agreed that hands-on activities should come before introduction of new vocabulary [10].

We have made a good start in improving the teaching and learning in a wide variety of science, mathematics, and engineering courses within our Collaborative. We are now in the process of using the courses that have been most successful in their changes as a nucleus of choices recommended for students who wish to be future science or math teachers. ■

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Bios

Charlene D'Avanzo is Professor of Ecology at Hampshire College. She has written numerous articles and edited books about student-active teaching, and she spearheaded production of the STEMTEC video, *How Change Happens: Breaking the Teach As You Were Taught Cycle in Science and Math.*

Richard Yuretich is a professor in the Department of Geosciences at the University of Massachusetts Amherst. He has helped transform the learning environment in a very large, general education oceanography course by applying the techniques mentioned in this article. Both authors are Principal Investigators of STEMTEC.

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IT'S FUN, BUT IS IT SCIENCE? GOALS AND STRATEGIES IN A PROBLEM-BASED LEARNING COURSE

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All students at Hampshire College must complete a science requirement in which they demonstrate their understanding of how science is done, examine the work of science in larger contexts, and communicate their ideas effectively. *Human Biology: Selected Topics in Medicine* is one of 18-20 freshman seminars designed to move students toward completing this requirement. Students work in cooperative groups of 4-6 people to solve actual medical cases about which they receive information progressively. Students assign themselves homework tasks to bring information back for group deliberation. The goal is for case teams to work cooperatively to develop a differential diagnosis and recommend treatment. Students write detailed individual final case reports. Changes observed in student work over six years of developing this course include: increased motivation to pursue work in depth, more effective participation on case teams, increase in critical examination of evidence, and more fully developed arguments in final written reports.

As part of a larger study of eighteen introductory science courses in two institutions, several types of pre- and post-course assessments were used to evaluate how teaching approaches might have influenced students' attitudes about science, their ability to learn science, and their understanding of how scientific knowledge is developed [1]. Preliminary results from interviews and Likert-scale measures suggest improvements in the development of some students' views of epistemology and in the importance of cooperative group work in facilitating that development.

Introduction

When Hampshire College was founded in 1965, its mission was to experiment with structural reforms of teaching, curriculum, and institutional design [2]. Faculty were expected to create new course structures that encouraged students to ask questions about what they wanted to learn about and what they were taught [3]. The science curriculum that evolved incorporates active learning strategies in courses and projects throughout the curriculum, starting in the first year [4].

All Hampshire students are introduced to science in small freshman seminars in which they engage in laboratory, field, or literature investigations. To complete the science requirement, students must demonstrate they have satisfied five criteria [5] that can be summarized as follows:

- Engage in scientific inquiry and develop a sense of ownership for their work
- Recognize and ask good scientific questions, assess the quality of experimental design, and examine relationships between data and conclusions
- Use quantitative information intelligently
- See the work of science in larger contexts
- Communicate ideas effectively orally and in writing

Students can't achieve these goals without learning and applying content and understanding the conceptual framework of their work. The "science" of the science requirement asks for more depth of understanding and a better ability to use information intelligently and analytically, than does a science requirement based on completing a class in which a certain amount of material about a subject in science has been covered. Students take science classes and they learn content, but that alone will not suffice. The challenge for faculty is to design courses that help students achieve these goals and to be able to recognize when students have succeeded.

College science faculty are not, typically, conversant with current literature on learning theory and teaching strategies. We design courses based on knowledge of our disciplines and on how they have been taught before. We may incorporate teaching strategies that worked for us as students or new ones that we heard about informally, but rarely do we search the education literature for ideas. This paper outlines the evolution of *Human Biology* over the past six years as we, along with other Hampshire faculty, attended Science, Technology, Engineering and Mathematics Teacher Education Collaborative (STEMTEC) institutes (supported by the National Science Foundation [NSF]), Project Kaleidoscope conferences, and a series of workshops at Hampshire College funded by the NSF Institutional Reform program (IR) and the Howard Hughes Medical Institute (HHMI). Through work with K-12 teachers, college science faculty, and educators from other institutions, we were introduced to strategies designed to promote active learning in science classes.

Human Biology: Selected Topics in Medicine is a focused, inquiry-based science course designed to help freshmen develop skills they need to complete the science requirement at

Hampshire College. A website for the class [6] includes details of the syllabus, instructions for groups doing casework, and expectations for students. This site also links to sources of medical cases designed for teaching human biology.

Described here are the structure of the course, changes made in the course over six years, examples of the kinds of work students did, and approaches used to assess student work. It was apparent as the course evolved that it was necessary to clarify the extent to which innovations in the course improved students' skills, knowledge, and attitudes about science. Preliminary results of assessments of introductory science courses at Hampshire College have been published or presented at professional conferences (such as the International Meeting on Science Education in Cuba, 1999), and we report here some of the findings that apply to this course [1,7,8,9].

The First Two Years

Six years ago, *Human Biology* was completely redesigned. A presentation made by M.A. Waterman (at Westview State College in 1995) at a Partners Advancing the Learning of Mathematics and Science (PALMS) conference—the Massachusetts NSF State Systemic Initiative—moved us to adapt the Harvard Medical School case-based approach for our undergraduate class. The first two years we taught the course, 30-35 first-semester college students worked in problem solving groups of 10-12 on three medical cases. The class met twice a week for ninety minutes each, and it included students who intended to major in science as well as students taking the course primarily to satisfy the science requirement.

Human Biology was not intended to be a survey of all human systems. Content in human biology consisted of material pertinent to the cases studied. We followed closely the approaches described by Waterman and Maitlin for problem-based teaching of medical cases [10,11], and we used medical problems based on real cases written for case-based teaching by faculty and staff at Harvard Medical School [12]. Each group included a faculty member or an undergraduate teaching assistant who facilitated discussion but did not lecture. After each case was solved, faculty gave lectures to provide background and depth students might have missed. Each student then wrote a detailed case report presenting the reasoning and evidence used to develop the differential diagnosis.

In the Harvard curriculum, cases are said to take 2-4 days to solve. In our class for freshman, cases were scheduled for six to ten classes (over 3-5 weeks), depending on the complexity of the case. Information about each case was presented to students progressively as needed. Teams organized their discussions around three questions:

- What do we know?
- What do we think we know? (list hypotheses)
- What more do we need to know?

The questions asked in response to "What more do we need to know?" fell into two categories:

- those that students could look up in resources we provided or recommended
- those that required more information about the patient (history or test results)

Separating questions into these lists helped students understand the difference between observations and interpretations. As recommended in the literature cited above, we did not answer questions or provide more information until students had thoroughly pursued material they could look up or work out themselves. When we did present new information, the cycle was repeated (Table 1). When all the case teams had narrowed down the final diagnosis with recommendations for treatment and follow-up, we gave out the final page, which usually confirmed their conclusions.

Case Approach
Teams receive and read "Page One"
What do we know?
What do we think we know?
What more do we need to know?
Teams assign learning tasks
Individual homework assignments
Report findings to team
Repeat cycle until case is solved

Table 1. Segments of each medical case were presented to teams who then followed this cycle of activities. The amount of time spent on each segment depended largely on the complexity of the case.

Throughout the case, students completed a variety of writing assignments (Table 2): some related directly to the case and others were designed to teach students to find and read analytically, primary research articles. Detailed explanations of these assignments are included in the class website [6].

Writing Assignments
Case logs
Interim case reports
Final report for each case
Statistics problems
Experimental design analyses
Article summaries and revisions
Final paper

Table 2. Homework assignments provided practice in finding and reading primary research articles and in developing background for the case groups.

The case team approach turned out to be a stimulating, challenging, and motivating experience for students. They spent lots of time in the library with medical texts; they gave informal presentations to their groups; they held lively discussions in and out of class; and, they wrote case reports and final papers that were more analytical than one typically sees from first-semester college students.

As faculty, we still had concerns that some of our goals for students were not being served. For instance, in previous versions of *Human Biology* we introduced students early to analytical reading of primary research articles [13]. In the case-team approach, students had no opportunities to examine experimental design and start to grapple with simple techniques of data analysis. We also noticed that although all students in the case teams appeared interested, three or four in each group were so quiet that we weren't certain how much they were learning until we read their final case reports. Conversely, some students tended to take over discussions and influence other students by their confidence, even if the information they presented wasn't always correct. We also found that the lectures we gave at the end of each case did not always answer questions students had, sometimes rehashed material they already knew, and often included everything we wanted them to know but feared they had missed. We packed so much information into one or two lectures (that we believed were well crafted), we suspected that much of it wasn't retained for long.

After the Institutes

As a result of what we learned in these programs and related literature, numerous small but important changes were made in the structure of *Human Biology*:

- group size was decreased from 10-12 to 4-6 students per group
- faculty did not sit in with any one group; instead, we listened in and moved from group to group
- strategies of formal cooperative groups were instituted [14,15]
- students were assigned team roles (facilitator, recorder, skeptic, fact checker, task manager) and given instructions about how to fill these roles [6]
- the semester started with short small group activities designed to build team skills and introduce the case solving process [16-20]
- mini lectures were integrated throughout the case in response to questions being asked, instead of being held at the end
- classes included times for low risk writing [21] to help students focus their attention on class activities or to articulate questions to ask us in class or privately
- students submitted short periodic reports on their case work before the final case reports were due
- feedback was solicited throughout the semester about what was working well for students and what wasn't
- peer evaluation of team participation followed the conclusion of each case (Course Packet/Peer Evaluation Form) [6]
- analysis by the teams of a primary article was substituted for one case
- jigsaw activities were used in which teams of students each learned one part of a primary article well, and those teams split up so that members of the original teams taught what they knew to those in their new teams [22]
- assignments focusing on statistical analysis of data presented in the primary articles were added

After we instituted these changes, more students took active roles in the groups, and all students knew they needed to contribute to group research and discussion. Almost immediately, it was possible for us to identify problems in group dynamics and misconceptions about the material and to respond to them. Students were very motivated and many did considerable library work and scheduled team meetings outside of class. When faculty acted as facilitators rather than leaders of groups, students developed their own strategies to direct their learning. They realized that they were responsible for making their groups work and that they needed to pull together information from a variety of sources to construct knowledge to resolve the problem.

Topics students chose for final papers were similar to those students wrote about in previous versions of the course. However after the changes we made, students' writing showed an increased understanding of the structure of primary scientific articles and how to properly cite resources, and most student papers included detailed discussions of two or three primary research articles. Sample final paper titles:

- Medical Assessment and Treatment of Pain
- Maternal Cocaine Use and Possible Effects on Perinatal Outcome
- Formation and Metastasis of Malignant Neoplasms
- Contemplating Creatine
- Gene Therapy: How successful is it really?
- Effects of the HIV Virus on Cellular Immunity
- Unemployment as a Risk for Cardiovascular Disease
- Causes, Impact, and Treatment of Polycystic Ovary Syndrome

Example of the Start of a Case

A typical case began by handing out a page that introduced the problem (referred to as "Page One"). This might be a summary of a patient's visit to a doctor's office and the symptoms the patient reported (medical history). Or, as in the example shown below, Page One might be an emergency situation that needed to be evaluated medically [23] with recommendations about what to do next.

Letitia Dorsi's Fall
Page One

On the night of October 25, 1992, Letitia Dorsi, a 53-year-old woman, was returning from dinner with her husband and asked him to double park while she ran into the drugstore to get toothpaste. On leaving the car and taking three fast steps, she tripped on a raised corner of concrete and fell flat.

She was holding a cape around her, so when she landed on the cement sidewalk, her knees, shoulder, and head all hit at once. She was winded and couldn't speak for a few minutes. Her glasses were broken, blood was running down her face, and her knees were scraped and bleeding. But when her husband helped her up, she insisted she was o.k and said she had to get home to prepare a lecture for class tomorrow. Despite her assurances, he drove her to the home of a doctor friend who lived nearby to see if he thought she should have stitches.

The doctor said, "The abrasions on your patella aren't deep, but they should be cleaned and dressed. The contusions on your head don't look too bad, and for cosmetic reasons you may want to get the flap and puncture-type lacerations stitched. But why are you holding your left arm like that? Given the brachial neuroplexopathy of your right arm, you'd better have your left shoulder looked at in the emergency room."

Students read Page One to themselves and then the team facilitator read it aloud. The student acting as recorder listed on newsprint, so that all team members could see, what the team decided they knew, what they thought they knew, and what they needed to know. Typically, case teams generated 10-15 items for each list. For the case shown above, students in one class listed (among other things): they knew Ms. Dorsi was 53 years old, married, fell on a sidewalk, and had some bleeding; they suspected she broke a bone in her arm, had a fainting spell, or had a concussion; and they asked, "How was she holding her arm? Did she really trip or did she fall for another reason? What is a brachial neuroplexopathy? Does she have medical insurance?" Technical terms were introduced early in the case so students could gradually build confidence using medical texts and dictionaries. Other pieces of information encouraged students to look beyond the obvious and find out more about the patient's history. Before class ended, team members assigned themselves questions from these lists to investigate.

At the next class, students shared the results of their homework assignments and constructed new sets of lists. The skeptic or fact checker was responsible for ensuring that information reported by team members wasn't accepted unconditionally: "How do you know that? Couldn't there be other explanations? Why would that happen?" This role was filled well by students who were confident about their background in science, but students who didn't think they knew very much biology often did the best job. Having the job of "fact checker" made it possible to ask questions the students honestly needed to ask. This process was repeated until the questions students asked could be answered only by learning more about the patient's history or test results. Then students were given "Page Two" ("In the Emergency Room...") and continued the process. Students can be seen working on a case about a hyperthyroid patient in a video [24] that focuses on a number of ways to use student-active teaching strategies in a variety of disciplines and classroom situations.

Formative Assessment

Students filled out feedback forms throughout the semester about the case process, content, and writing and library assignments. This feedback was invaluable to us in understanding what was working well and what mid course changes we could make. Sometimes when students expressed confusion or frustration, changes weren't necessary. Such comments provided openings for reminding students of our expectations of them and how the course structure was designed to support them. As we gained confidence that the goals were achievable and the approaches worked, we were better at conveying this to students and they were more confident about their progress.

Early in the semester, many students expressed concern that they wouldn't get the "correct" diagnosis. This provided a good opening to talk about the nature of evidence in actual medical situations in which the medical practitioner doesn't have an answer sheet at the end of the chapter. As they worked through cases, students learned about the importance of considering a full range of possible solutions and figuring out ways to eliminate those that didn't fit the symptoms or test results. We told students that they should avoid jumping at easy answers because they might miss a more important or subtle diagnosis. In addition, emergency situations, such as a patient with intense chest pain, required them to respond to possibly life threatening diagnoses such as myocardial infarction, before calling for tests to eliminate others (e.g., esophogeal reflux or muscle strain).

Often students asked what would happen if they came up with a diagnosis different from that eventually presented in the case. Our response was that if they could defend that decision effectively, they would have done a better job than if they happened on the "correct" diagnosis by luck without having reasons to back it up. Even if they chased down unlikely diagnoses that they eventually eliminated, they would have learned more biology than if they hadn't done that, and our evaluation of their work would reflect that effort and imagination.

Assessment of Student Work and Evaluation of Course Goals

At Hampshire College, students receive one page narrative evaluations of course work instead of letter grades. At the end of the semester in *Human Biology*, each student submitted a portfolio that included all written work and a reflective self-evaluation. Students also submitted peer evaluations of their contributions to team work [6]. By reviewing the semester's body of work for a student, we were able to assess students' progress in satisfying the five criteria listed for completing the science requirement.

The NSF and HHMI programs supported evaluations of course innovations. This made it possible to determine the extent to which the course helped students develop skills needed to satisfy the Hampshire College science requirement. Outside evaluators developed pre- and post-course questionnaires, performed in-class observations, and conducted structured interviews with randomly selected students at the beginning and end of the course. Information was collected about students' attitudes and beliefs about science, critical thinking abilities, self-reported gains in skills, backgrounds in science, and interests in pursuing science further.

Much of this assessment was coordinated, carried out, and reported by Laura Wenk [7] who worked with an assessment group from Dartmouth College (Evaluation Works, Korey Associates based in Norwich, Vermont) and one from the School of Cognitive Science at Hampshire College [25]. Our course was one of eighteen introductory science courses Wenk and her colleagues studied at two four-year colleges.

We were interested in examining changes in students' epistomology in science. That is, what was students' understanding of the nature of scientific knowledge? More specifically, what methods did students use to justify decisions and what was their understanding about how scientific knowledge is constructed? Data about these developmental issues were collected from students in introductory science classes through three means: pre- and post-semester interviews with students chosen randomly (faculty did not know which students were being interviewed);

pre- and post-semester Likert-scale surveys on students' attitudes and beliefs about science; and, post-semester Likert-scale student self assessments.

Preliminary results of the Likert-scale surveys showed that for most items on the surveys students showed positive trends but no significant improvements in their attitudes about science [8]. Nonetheless, those items that did show significant improvements had to do with greater appreciation of scientific thinking and greater understanding of the nature of evidence in science. Wenk reports that significantly more students agreed at the end of the course with statements like the following: "Even if I forget the facts, I'll still be able to use the thinking skills I've learned in science"; "I can back up my ideas in science." [8] Students disagreed more strongly with the statement, "Scientists publish their work in professional journals that are too technical for me to understand." In self-assessments, students noted that they felt better able to use scientific evidence to support their ideas, they could more critically evaluate a primary research article, and they could make better judgments about science issues reported in the newspaper.

In one of the workshops for science faculty, Wenk outlined current thinking about stages in adult understanding of how knowledge is constructed (Table 3). Literature reviewed by Wenk suggested that college seniors are typically at stage four or five and move to stage six after they've spent time working or in graduate school [8]. Faculty found that this developmental perspective offered a strong analytical tool for understanding progress in students' thinking. For example, before we recognized the existence of intermediate stages, we expected that first-year students who took one of the inquiry-based courses would jump from believing that knowledge comes from authorities to using rules of inquiry to understand evidence in context. We were disappointed if a student who wrote an excellent critique of experimental design and analysis of data suddenly approached a conflict in the literature by saying, "Well, everyone has his or her own beliefs, and that's o.k."

After Wenk's workshop, we were able to recognize significant progress in the development of students' ways of thinking that previously we had regarded as failures to reach our goals. Science faculty not familiar with the underlying research of stage theory wondered if these stage descriptions were somewhat arbitrary, but many of the ideas summarized in Table 3 rang true to most faculty who regularly read student papers in science.

Summary of Adult Developmental Stage Theory	
Stage	**Epistemology and Method of Justifying Decisions**
1	Knowledge is certain; authorities have the right answers.
2	Knowledge is certain, but disagreement sometimes exists. Decide based on what authority tells you.
3	Knowledge is certain in some areas, uncertain in others. Authorities may disagree because of bias. Decide based on what feels right.
4	Knowledge is uncertain. Everyone has his or her own beliefs; some are more logical than others. Decide based on evidence that supports beliefs.
5	Knowledge is uncertain, but some ideas are supported better than others. Look at evidence in making decisions. May need help in evaluating evidence.
6	Knowledge is known within a particular context and is limited by the perspective of the knower. Decide based on evidence, using rules of inquiry for that context. Disagreements may be due to contextual variables that the student can name and understand.

Table 3. This chart was adapted from Wenk [8] who synthesized ideas from developmental theorists such as Perry, Belenky, Magolda, King, and Kitchner

Excerpts from one interview reported by Wenk illustrate how interviews can provide evidence about students' understanding of the scientific process [1]. One student's response to the statement, "Every day, in more and more areas of science, the right answer is known. I look to experts to tell me what is right. In areas where no right answer is known, I think anyone's opinion is as good as another's" is excerpted in the quotes below from their pre- and post-course interviews:

Pre-course:

I think I agree with it basically....when there is a right answer that you know is going to be right and that you have the possibility of getting the answer wrong, then you just look to someone else to give you the right answer to teach you how to get the right answer. In areas where no right answer is known, I think anyone's opinion is as good as another's...

Post-course:

I think they kind of have this thing backwards a bit. I don't think that every day in more and more areas of science the right answer is known.... My mind has really started to change since I've been in school just about the way things work...It just seems like there are a lot more factors to it than just being like 'this is a study that came up with the right answer and this one says that it came up with the right answer too and so one of them is right and one of them is wrong'....It's more like maybe this study did it differently and maybe they went about it differently and maybe they were trying to find out something different....

One of the most interesting findings of Wenk's work is that with no teacher in the group, students were required to rely on their own research and problem solving skills more. Interviews with some students suggested that working in small groups without an instructor in the group helped students develop more sophisticated strategies for coming to decisions than would have been possible if students worked alone and turned only to faculty for answers. For example, if the information one student found supported one hypothesis and the information another student on the same team found rejected that hypothesis, each student needed to justify the diagnosis they presented with evidence. They couldn't just say, "One person's opinion is as good as another's." They needed to dig deeper, compare the information in more detail, re-examine the original hypothesis, and develop others. Many students who wouldn't have had the confidence to carry on this kind of critical discourse with a faculty member did so with other students.

What We Learned

So is this science? We think so. On the basis of Wenk's survey data and her interviews with students, we are more confident that students in the course are learning science [8]. They read and evaluate scientific studies to learn how scientists ask questions, design experiments, and evaluate data. Their summaries of these papers show healthy skepticism as well as an appreciation of the limitations to designing perfect experiments. The final papers they write for class demonstrate that they learned and can use content necessary to read and write about scientific questions with some confidence. What's more, their work shows that as they gain confidence in what they can do and what they know, they start to understand how much they don't know, but that doesn't discourage them.

Is it fun? Excerpts from self-evaluations of four students are typical and sound as though the students are enjoying the course, even as they are working harder:

"Being faced with the challenge of finding large amounts of information that was relatively new to me and actually going out and finding it created in me a great sense of accomplishment."

"I enjoyed the way the class was structured."

"The cases definitely tested my ability to revise and re-think and revise again."

"I must say that I am very proud of my progress."

Is this course perfect? Not even close. But we are much closer to achieving our goals for students than ever. Changes made in course structure as a result of what we learned in curriculum workshops helped us solve our original problems. Students show:

- increased motivation to pursue work in depth
- more active participation in case teams
- deeper critical examination of material gathered from medical texts and journals
- greater development of arguments in case reports

We have learned a lot from colleagues across the country. Resources exist for faculty who want to learn how to use case-based and problem-based learning in science courses [15,17,26]. Many faculty write their own cases and publish them in journals and on-line for others to use [27]. Each year we look forward to working on new cases. We're still having fun, too. ■

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PROJECT- AND GROUP-BASED LEARNING OF *JUNIOR WRITING IN BIOLOGY*

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Writing in Biology, part of the Junior Writing Program, is inherently a project-based learning course. After a Science, Technology, Engineering, and Mathematics Teacher Education Collaborative (STEMTEC) workshop, the course was thoroughly revised. Each of six projects was modified to increase student-active and group participation. Base groups with a balanced experience constitution are established using voluntary ordering and random assignment. A walk-around during the initial meeting serves to establish bonding within the base groups. Random groups are used within exercises to stimulate student interaction and familiarity with ad hoc group cooperation. Digital images of, and by, students are used to encourage student interaction and name recognition. A website with the entire course plan is available at an archival site to complement and help elucidate the course.

Introduction

In the University of Massachusetts Amherst Department of Biology, the Junior Writing Program [1] is a University wide program and a degree requirement for undergraduates, and is implemented as the course *Biol 312: Writing in Biology* [2,3,4]. It is assigned to faculty who are assumed to have their own outlook on what the Junior Writing Program requirements should be. Indeed, the University has been flexible in allowing each department to define the guidelines for teaching its own majors the writing skills important to its particular discipline.

In that framework, I have been teaching *Writing in Biology* at least once a year for the past twelve years, with the exception of a sabbatical year spent off campus. That twelve years spanned the development of the World Wide Web and microcomputer resources on campus and in my department, and these have had a dramatic influence on the ease and direction of teaching courses. In Spring 1996, I instituted the first use of a home page for my *Writing in Biology* course [2], and I then participated in the Science, Technology, Engineering, and Mathematics Teacher Education Collaborative (STEMTEC) [5] Cycle II workshop in the summer of 1998. STEMTEC has had a fundamental and far reaching influence on my teaching approach to this course, and perhaps also on my teaching style in general. I must preface this endorsement of

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STEMTEC with the warning that I was an early convert to using computers in education, including early attempts to use the University Computing Facilities to teach biometry using the APL language with the teletype terminals available to us in the 1980s. Thus, some of my efforts to implement and encourage my students to use computers is wedded to my own career-long use of and devotion to mathematical approaches and computer implementations of data collection and analysis. For a scientist, that cannot be bad, in my eyes. Whether my degree of emphasis on computer technology for undergraduate education is appropriate, is itself debatable.

Using strategy I learned in STEMTEC, I derived very practical methodology for implementing group-oriented learning as well as project-based learning approaches. This methodology fit in very well with my earlier feelings that the most intense learning experiences were those with hands-on contact on a learning focus. On the other hand, my earliest teaching approach was wedded to my college and graduate learning experiences, where the majority of my professors spent their class time lecturing. The incongruity between how I had best learned as an undergraduate—"hands-on" experience—and how I was teaching my students continued to perplex me until I attended a STEM colloquium on teaching methods (spring of 1998). A talk entitled, "Teaching Human Biology through Medical Cases," by Dr. Merle Bruno caught my attention. This peek at an enlightened approach led to my participation in STEMTEC Cycle II in the summer of 1998.

In this paper, I will describe how the *Writing in Biology* course has developed with the aim of making its methodology available to others teaching similar courses. It is sometimes hard to imagine students learning without the inspiration of their professor at the head of the class. This description of my progress in teaching *Writing in Biology* is an attempt to redefine my own role as director in a classroom and whose students are involved in managing their own learning experience.

Materials and Methods

The methods used in teaching *Biol 312* (Table I) can be precisely described if not precisely applied. I will discuss each method to explain its utility and implementation in the course. Some of the methods were acquired during the STEMTEC Cycle II workshops and some were developed through an evolutionary process in the classroom.

Table I. Methods used in teaching *Biology 312: Writing in Biology*
Six formal student projects (60% of grade).
ad hoc assigned projects (40% of grade).
Course home page, e-mail list, calendar of events, syllabus and notes.
Base group implementation.
Random groups used ad hoc.
Blacklist Errors establish a code which should not be violated.
Digital images of students increases student identification.
'E-mail 3 then me!' to encourage student-student interaction.
Mini-lecture organization.
Case-based organization.
One-minute essays e-mailed to instructor.
Laboratories are used to complement the projects: A. Careers Day held along with Vita/Résumé project. B. Excel workshop associated with Technical Report project. C. Library and Informational Database searching.
Overall focus on student ownership of a "Term Project."
Terminal symposium of student projects.
Peer comments and grading of Term Project talk.
Students develop Rubric for grading projects.

Six Formal Student Projects

The learning experience in *Writing in Biology* revolves around six formal projects (Table II) which represent 60% of the student's final grade. Completing the six projects involves the core communication skills that I decided need to be developed to an acceptable level of proficiency in any student who wants to be considered a modern biologist. These are described below. Students are given sufficient time (at least two weeks) to finish each project and in most instances, have the opportunity to resubmit it once and get re-graded. The new grade is averaged with the old, therefore pressure exists to get it right the first time. Also, the right to redo a project is absolute only if the project is submitted on time, thereafter it becomes negotiable.

Table II. Six Formal Projects of *Writing in Biology*	
Project	**Special rules**
Centered Abstract	Hard copy, electronic, and redoable
Curriculum Vitae	Hard copy, electronic, and redoable
Technical Report	Electronic only, and redoable
Annotated Bibliography	Electronic only, and redoable
Popular Essay	Electronic only, and redoable
Poster / Talk	Poster or talk, one time only

The Centered Abstract - This project is used as a method of introducing the student to the concept of being in total control of a finished writing product which must fit in the constraints specified by a conference at which they will be presenting their ideas. They are given basic guidelines to follow: (1) sources of subject matter (*Scientific American*, *New York Times*, or *Science Times* essays on biological subjects for the past six months); (2) instructions on placement of the abstract within a prescribed space on an 8-1/2" x 11" page; (3) instructions on required and optional formatting; (4) must be turned in as hard copy in the specified format and as an attachment or insert to e-mail in a limited number of formats (flat text, RTF attachment, URL pointer).

Curriculum Vitae - Students are made authors of their self descriptions. This allows students to describe themselves in their own best light. It produces a document which they may find difficult to assemble at a later time under pressure. At this time, they can begin defining a look back on their careers and assemble information which will be a foundation for their future. This project must be turned in as a hard copy and as an attachment or insert to e-mail in a limited number of formats (flat text, RTF attachment, URL pointer).

Technical Report - Every science student has been called upon at least once to produce a lab report, yet it is rare that one gets to spend time on the format of an ideal form of such a document. The skills learned in this process could have major consequences for the professional advancement of students in their disciplines. Students who are doing independent study in a university lab are encouraged to use this Technical Report project to develop their final report for their independent study. This project must be submitted in an electronic form with one or more of a limited number of formats (RTF attachment, URL pointer).

Annotated Bibliography - Writing without intellectual rigor is worthless. In this project, students learn to use modern library resources including on-line catalogs and reference gathering from databases such as Medline and Web-of-Science. The difference between a core reference from a refereed journal and a URL from the World Wide Web is defined. Electronic processing of searched for information must be performed to bring it together into a consistent format of a bibliography. Capturing essential information from a reference in an annotation limited to two sentences develops the skill of interpretation and summarization. This project must be submitted in an electronic form with one or more of a limited number of formats (RTF attachment, URL pointer).

Popular Essay - While scientists need to be able to understand technical information, professional scientists also need to be able to communicate their expertise to the public. The popular essay allows students to translate, for popular consumption, their expertise gleaned from reading technical journals and analyzing graphs and charts. If students truly understand their subject, they will easily convey it in plain language understood by the layman. This project must be submitted in an electronic form with one or more of a limited number of formats (RTF attachment, URL pointer).

Poster/Talk - Written and spoken communication are quite different and require separate skills. In this project, the students learn how to present their topic to fellow students either as five minute talks (+ three minute discussion) to the entire class or as posters which they explain to a small audience in a simulated poster session setting. This project includes an abstract that must be submitted electronically by a deadline. It must be presented live at a symposium session scheduled at the end of the term using either the physical poster with a presenter or a five minute talk format using overhead and/or *PowerPoint* projections. The students grade all the presentations according to a rubric which they have helped produce. The students also vote for a single top presentation that has no bearing on the final grade.

Ad Hoc Assigned Projects

Class assignments are meant to be completed in a short prescribed time, perhaps within the laboratory period in which they were assigned. They involve immediate hands-on learning or cooperation within a group to accomplish the task assigned. When they are to be graded, students must have a tangible result that can be assigned a grade. The immediate objective of the assignment may be trivial, while the skills learned through the process of group activity, cooperation, and communication may be the ultimate objective of the assignment. The types of ad hoc assignments include one-minute essays and random-group activities.

One-minute essays e-mailed - The availability of student computer stations in the University Microcomputer Labs and Biological Computer Resource Center (BCRC) [6] allow one to stop a learning segment and inject a one-minute essay which is e-mailed directly to the instructor. In another version, the minute essay is e-mailed to another student who then must respond with commentary or criticism.

Random group activities - In order to allow for variety in student interaction, several ad hoc group assemblages were used. Several methods of ad hoc grouping were used including, nearest neighbor pairs, nearest birthday pairing, and jigsaw grouping (a disassembly of the base groups sending delegates to select focus groups). The objective is a greater mixture of interactions between more students in the class. Typically, the groups created were assigned a task that required or would be aided by cooperation within the group.

Walk-around - During the initial meeting of the class, there is often little concrete to do that falls within the project-based nature of the course since no projects are yet established [7]. In getting the students acquainted with their base group, as well as group dynamics, a standard walk-around student activity was devised. The students, in their base groups, first walk around five to six stations, each with an initially large blank poster with a controversial question posed. The group discusses the question and adds some written response to the sheet using a colored marking pen. After five minutes at each station, the groups rotate to another station. The class is next randomized into six different groups who go to one of the stations and evaluate the responses the base groups had added to the posters. Then, a representative from each group presents the conclusions of the poster. This walk-around activity gives the base group and the class as a whole an opportunity to converse and get to know each other in a semi-relaxed atmosphere. The leader or designee takes time during the rotations to take pictures of students and their groups for use in other class projects

Course Home Page, E-mail List, Calendar of Events, Syllabus and Notes

It became efficient to present this course in this format because of the availability of easy communication over the Internet as well as the promulgation and availability of computers and software for communication. The convenience of having supportive documents and instructions on-line and being able to communicate in multiple ways (instructor ⇔ student ⇔ student) allows for a different dynamic in the learning process. The work of the classroom extends to wherever there is a computer terminal on the Internet.

By 1996, the Department of Biology had made an investment in a computer resource center, the BCRC, which included an electronic classroom with 25 computerized student stations. In addition, a SPARCstation 20 was provided to serve as a server to integrate the lab with other ancillary equipment, such as printers, slide and flatbed scanners, and cameras. The SPARCstation also provided a powerful Unix box separate from the department's workhorse that could be used as a web server devoted to teaching projects. This investment was a conscious commitment by a department to embrace the electronic aids to teaching.

In addition, a full-time faculty position was funded to provide an education professional whose research interests and expertise lay in the application of technology to teaching. Without the foregoing commitments of the Biology Department, I would have found it difficult to make the changes in my teaching approach that are listed here.

Even with all the physical support by the University and the Biology Department, establishing an effective course delivery would be difficult if aspects of its delivery were not made routine for the student as well as the instructor. For that, we biologists are indebted to the director of the BCRC. He adopted and managed a system of software that provided a uniform Internet interface for all Biology Department course offerings (whether it was used or not). Links to a course syllabus and a course e-mail list make information and communication about the course available to the student at a click of the mouse. A calendar of events with hyperlinks to the project descriptions allows students to know more precisely what is expected of them to make progress. Workshops are scheduled to help faculty make use of the internet utilities available to them.

These improvements in teaching technology do not happen without support from a committed administration. One can not underestimate the importance of a department chair and college dean who manifest their commitment to improved teaching technology in an enlightened way.

Base Group Implementation

Students were randomly distributed according to expertise into base groups, four students to a group. This was accomplished by first asking students to divide into three levels of experience in information technology (IT) methods, including word processing, spreadsheet analysis, and Internet skills. Then these groups were placed in a long line that counted off 1-6. This created six groups, each having high to low IT skilled members. The base groups would provide a nucleus within which group cooperation and individual roles could be practiced. Leader, recorder, skeptic, and reporter roles provide each group with the opportunity to cooperate in carrying out class assignments in which division of labor would benefit the group as a whole.

A Blacklist Errors Document Establishes a Professional Code Not to be Violated

To be a professional biologist, major errors in communication should be avoided. Highest on that list is plagiarism, a professional form of cheating. However, the concept of plagiarism is presented in its professional context where scientists need to preface their own contributions with the citation of ideas contributed by their science forebears. Professionals must be able to reflexly recognize when ideas they are presenting are not their own and give proper credit to the authors. Thus, one avoids being labeled a plagiarist by using the research tools of the library to ensure respect of past contributors. Second on the communication blacklist are grammatical and spelling errors that lower respect for the communicator. A list of these key errors is posted and each error committed in an assignment or project is an immediate reason for grading down the student's work and reinforcing the elimination of that erroneous behavior.

Digital Images of Students Increase Student Identification

On the first day of the semester, digital images are taken of each student. The images are used to improve greater cohesiveness in the class. Teacher identification of the students is improved. The images are posted on the class web page, used in a group identification assignment, and are available for the students to enhance their own web pages.

"E-mail 3 then me!" to Encourage Student-Student Interaction

An e-mail list for the entire class as well as individual addresses for each student are listed and students are encouraged to e-mail the entire class and one another when they run into problems. Many students will reflexly e-mail the instructor for answers to questions. In an environment where e-mailing is encouraged, this can result in an overwhelming number of e-mails to be answered by the instructor. To encourage a more even distribution of e-mailing within the class, the ***"E-mail 3 then me"*** rule was established. This rule suggests that the students should address routine informational questions to at least three other class (or world) members before they e-mail the instructor. Points are given for posing and answering substantive questions to the entire class through the class e-mail list. These are awarded as bonus points at the end of the semester.

Mini-Lectures

In breaking out of the traditional hour-long lecture format of traditional university courses, the “lecture” and “lab” meetings of the course are broken into short mini-lecture segments. These mini-lectures are interwoven with evaluation and student-active segments in which the learning of the mini-lecture is consolidated by an assignment that practices the new skills.

Case-Based Organization

In a case-based approach, one supplies a rich problem plus the tools to solve the problem, to either individual or groups of students. The objective of this approach is to get students to be reflective of their current stage of development and to learn to choose the proper tools and use them in solving a problem they might run into in their chosen professions [8]. It is a teaching method being used in professional schools to get students involved in an approach as they might apply it in the real world [9]. Application of case-based methods to undergraduate science education is less common [10].

I have used the Goldenrod Gall case [11,12] as a theme in one laboratory to create the rich fabric for students to investigate. This particular case-based example requires a wet/dry lab learning facility that allows the students to manipulate biological material and simultaneously record observations on computer terminals.

Most university wide computer classrooms are not designed to accommodate this type of special learning experience. This is a reason for designing computer classrooms at the departmental level (here, the Department of Biology) so that the peculiar requirements of a discipline may be accommodated during the planning stage.

Laboratories Complement Projects in Tool and Skill Development

The six formal projects are rich in detail as projects in themselves, and need explanation and help to be properly approached by the students. The projects can be enriched by independent exercises that are assigned in laboratories run in parallel with the projects. For example, a Careers Day was held at the time of a Vita/Résumé project; and, an *Excel* workshop was held paralleling the need of such tools for the Technical Report project. The primary concern remains the development of critical skills in each student.

It is hoped that the assignments and enrichment exercises will develop a professional sense of differences in value of: (1) primary references from peer reviewed journals; (2) reviews of the field by experts in their field; and, (3) reviews by professional writer commentators; (4) commentary obtained in non-peer reviewed URLs.

Students Develop Rubrics

The basis for grading of two of the six formal projects is discussed and modified by the students using random small groups. A student-developed rubric establishes what is expected and what would constitute loss of credit for the two projects at a time when the students should be preparing to carry out the project. Owning the rubric allows students to focus on the fairness of various reasons for loss of credit and focus on the objectives of the project.

Student Ownership of Term Project

While an atmosphere of availability of support for all types of technical issues is encouraged, each student is expected to become the local expert in their Term Project. Ownership of that project is used as a confidence building tool. Students are encouraged to speak about their projects at several points in the semester to develop their ownership of the topic. Any duplication of projects is turned into pressure to differentiate the approach taken by the superficially similar topics.

Terminal Symposium During which Students Share their Term Project in a Presentation

A symposium is prepared at the end of the semester in which students provide a final abstract on their term project and give a 5-minute talk with additional minutes for questions and discussion. A student photographer takes digital images of the proceedings to give the students an image of how they appeared on stage and to apply a level of pressure on their performance. When there is not enough time to present all projects as talks, the overflow is allowed to use a poster session format.

Peer Comments and Grading of Term Project Talk

Students participate in the grading of the abstract and oral part of the Term Project talk.

This is one of the formal projects for which the students helped to develop the rubric. The preparation of the rubric allows them to contribute more effectively to the grading process.

Results

The content of *Writing in Biology* has changed in the twelve years that it has been offered in this format (Table III). While it was always a project-based learning experience, the way *Writing in Biology* is taught has changed dramatically. Initially, a large amount of time was spent in the traditional mode of expert-professor transferring information to *tabulae rasae* students. I now recognize that most of that lecture time and "expert vs. empty-vessel to be filled" attitude was a misuse of time. While students in project-based learning regimes benefit from being overseen by an expert [13], the majority of students can rarely retain and digest the material provided in long lectures by such an expert. Now, more emphasis is put on students experiencing hands-on solutions to their own communication problems, using the information resources that are available and only one of which is a professor. Communication among the students is encouraged by the formation of formal and informal groups whose objective is to cooperate and communicate. Tools, similar to the ones they might use to solve problems, are provided and they have instructions, group partners, and local experts to consult in how to use the tools. All students can advance at their own pace using the available resources, but all students are also judged against minimal standards specified in the Blacklist Errors document.

The major global factor in the change of approach to teaching *Writing in Biology* has been the increased availability of IT; in particular, the personal computer, the Internet, and e-mail. These tools have allowed the teacher to expand the experiences that can be presented to the student in a learning environment. Before, communication was hampered by the need for face-to-face communication or often through scribbled handwriting. Digital personal computers provided a way of recording and transmitting, first by printed output, then by e-mail and finally by attachments of digital documents, including images, to e-mail. The Internet allows lecture notes to be provided on-line. In addition, the introduction of the Hypertext Markup Language (HTML) allows 'hyperlinks' within the notes to provide further enrichment of the lecture material by rapid (one mouse click) linkage to ancillary information. This ancillary material may be developed locally by the instructor or may be available on the web (e.g., the U.S. government has financed the free availability of bibliographic, genomic, and taxonomic databases via the Entrez search engine). Teaching students how to access this rich resource which is expanding every week, is empowering them to join the new IT century. Not teaching them to access this resource may lead to a new level of illiteracy, information age illiteracy.

While global factors establish the limits of what is possible, often local factors limit what can be accomplished. The major local factors in the changes introduced in *Writing in Biology* have been the institution of the Microcomputer Resource Facilities by the University Office of Information Technology (OIT), the development of the Biological Computer Resource Center (BCRC) by the Biology Department, the hiring of support staff, the progressive ethernet wiring of our department and campus, and institution of the STEMTEC organization. IT started in earnest in the Biology Department in 1988 when our then departmental electronics specialist, George Drake, was encouraged by our forward looking Dean Fred Byron to install ethernet wiring in our building, the Morrill Science Center. At that time, Chris Woodcock and I were bemused by our new ability to e-mail each other and George from our desktop computers. We were more impressed with being able to store data and access it on a disc drive attached to our Unix based minicomputer which was a floor away from my office computer. It was challenging to take advantage of the subsequent exponential increase in resources that were made available by these foregoing factors.

Table III. History of significant facts and actions contributing to the evolution of *Biol 312: Writing in Biology* (as taught by JGK)

1988	Prehistory and Infrastructure	The Biology Department is wired with ethernet. Faculty gets e-mail.
		University establishes PC based lab classrooms.
		Writing in Zoology under JGK begins using the University PC classrooms.
1994	Necessary commitment of funds	Howard Hughes Foundation funds a Macintosh based Biological Computer Resource Center (BCRC).
1995	Individual effort	JGK learns HTML programming, as well as the Macintosh platform.
1996	New Investment	JGK uses HTML to establish the first website for *Writing in Biology* .
		A director of the BCRC was hired with Biology faculty member status.
1997	Providing Tools	BCRC director implements a home page for every biology course. STEMTEC Program is established to stimulate teaching improvements in science and technology.
1998	Synergy	JGK participates in the STEMTEC Cycle II workshop.
		JGK implements group- and project based approaches to *Biol 312.*
		SARIS report finds 65-70% of UMass Amherst students use computers.

Many new as well as older professors found it difficult to take advantage of these opportunities given the pressures to maintain expertise in their own research specialties. The recognition of this fact by the Biology Department led to hiring a professional director of the BCRC in 1996 to implement mechanisms which would help the faculty include IT methodology in their teaching. The current director was identified by a committee, cognizant of our growing need for expertise in the areas of IT, instructional technology, and instructional software. Without the thoughtfully constructed resource that our BCRC director provides, I am sure that progress in transforming the teaching of biology at our university would be considerably less advanced. Unfortunately, the decisions for designing and acquiring the BCRC facility were carried out while I was on sabbatical and the committee went entirely with Macintosh computers. This required that I, a dedicated PC user, learn the then substantial differences involved in using the new computers. In the ensuing years, the differences in software and file compatibility have decreased and divisive pressures on the students (who are also mainly PC owners) have subsided. This is a familiar story, and a reason it often takes substantially greater effort to innovate techniques. Reduction to routine practice often takes several years. In that respect, the IT and teaching technology advances need to be encouraged by an understanding administration that values the efforts put in these new directions.

The implementation of *Writing in Biology* evolved over several years. In the initial years, 1988-93, the availability of microcomputers or word processors was not universal among students, particularly students at a state university, drawn from all economic levels. Only a few public microcomputer labs of about twenty computers were available for a population of over 20,000 students. Personal computers were not yet an essential part of each student's personal property on campus and the few that had computers were not yet connected to the Internet, itself a new concept on campus.

When I started using the University Microcomputer Labs for teaching skills in *Writing in Zoology*, I considered the use of the microcomputers an optional enrichment and did not feel comfortable in absolutely requiring students to hand in all their writing projects typed or printed. That meant teaching *Writing in Zoology* involved the pain of reading often horribly handwritten assignments. Two classes of students developed, those with and those without easy access to a microcomputer and printer. This contrasts with the subsequent gradual development of easy access to university-wide microcomputer facilities with ancillary printer output capabilities.

It is interesting how back then, the perceived major controversy over who would pay for all that paper was resolved. It was remarkably decided that the cost of a few reams of paper was less important than encouraging the use of the new technology. "If you make it next to free, they will come!" It is (was) an important transition to the paperless society. Making this technology easily available to the students enabled me to require students to submit writing assignments printed and, more recently, as attachments to their e-mail or posted on their personal web pages. Each step moves closer to the paperless and minimal energy use society which is making our country more productive. Receiving their digital homework allows me to use spell checkers and grammar checkers to filter the assignments prior to reading them for intellectual content. What a difference twelve years has made!!

The technology, of course, has gone through its own painful development. Early e-mail utilities did not have convenient editors with spell-checking capabilities and this led to a decline in grammar and spelling skills since everyone was supposed to accept the poor construction that attended the new way of communication. Advances in e-mail utilities now allow me to demand the same careful preparation of e-mail messages as I demand for essays.

STEMTEC Contribution

By far the greatest change in the format of the *Writing in Biology* course was implemented after I took the STEMTEC Cycle II workshop in the summer of 1998. Previously, I did not use grouping of students at all in my teaching of this course. The approaches introduced by the workshop resulted in introducing base groups, random groups and jigsaw groups as ways of introducing cooperation, organizational role play, and communication between students. Prior to my STEMTEC experience, grading was dependent solely on six formal projects. After STEMTEC, I implemented new features such as graded ad hoc class assignments which both engaged the students and gave them a reason for coming to class. Most of student work on formal projects could still be completed by using the already implemented on-line descriptions of the projects. To encourage students to come to workshops which I designed to enrich their formal project implementation, I linked the workshop with the project using *grading. I* linked related workshops with projects; i.e., participation in a committee based career search was linked with their formal CV preparation project. I linked a spreadsheet workshop to parallel their formal Technical Report project in order to provide the skills for accomplishing their formal project. However, it was the short, graded, ad hoc assignments during the workshops that required their attendance to carry out if they valued the 40% of their grade dependant on class assignments. Thus, it was an unanticipated combination of student active exercises plus ad hoc testing that had a positive effect on class attendance.

Grading the Project- and Group-Based Course

Some of the formal projects and ad hoc assignments fall into the traditional grading scheme of quality points given for how close one comes to the ideal response described in a rubric for the project. Before STEMTEC, the rubrics were loosely defined by the instructor and sometimes not well explained to the student. By involving the student in assignments in which they constructed, modified, and presented proposals for modifying a project rubric, through interactions within a small group, both student and instructor became more cognizant of the objectives of the projects and what were legitimate bases for grading. However, it is in general harder to grade the various ad hoc assignments that are spawned during the class periods. Rubrics for these assignments cannot be spelled out too completely since there is often only a short time given for their completion (e.g., a one-minute essay on a subject to be transmitted immediately by e-mail to the instructor). Deadlines for submission are often not met and some credence must be given to the reasons for tardiness as well as credit given to those who meet the deadlines. In addition, many of the class assignments use groups to accomplish the goals. How does one gauge the performance of individuals within the group? When a group with a missing member during a given week carries out an assignment, does the entire group benefit or suffer from the assigned grade? These problems often need to be dealt with in a very individual way that may cause some questions from students.

Advantages of the Web Page Based Course

In the past, one's image of progress in the development of a course was almost totally based on memory and perhaps notes about how things went that semester and one's grade book. Now, biology course web pages are routinely archived each year by the BCRC director providing a detailed history of the electronic course material [2,3,4], and, if designed into the site by the instructor, includes examples of student work [14]. Previous years' results can be a basis for current course projects. Students can view the results of prior classes. Archived pages make updating easier for the instructor and attention can be given to enrichment in succeeding semesters. Instructor-archived assignments and course web pages at critical times during the semester can be a record of student progress within the semester and can help in initial grading, as well as resolution of controversies at the end of the semester. At some point, when enough years of archived courses are accumulated, this archive could be a subject of study by educational research specialists on the effectiveness of various teaching approaches. In fact, the problem of evaluation of the effectiveness of teaching innovations and technology is one of the most vexing problems in educational funding.

The Future of *Writing in Biology*

I hope that *Writing in Biology* will persevere in its student centered objective of producing biologists who are well trained in communicating with their fellow biologists and the world in general. Accomplishing this objective will require the continued cooperation of faculty, administration, and taxpayers to keep our technology close to the forefront of IT. This is particularly challenging in an atmosphere of pressure to reduce taxes without reducing educational services. The electorate must understand that you rarely get more than you pay for. The Howard Hughes Foundation grants that were used to enrich our biology educational environment carried a stipulation that the University carry on some of the innovations that were funded by this charitable trust. This means that some of the burden of maintaining our new IT facilities and educational approaches will fall upon the federal and state taxpayer or tuition payer. Unfortunately, too much attention is being paid to glorifying individual teachers who expend superhuman effort for their students. As admirable as these individuals are, education cannot depend upon having such great teachers of extraordinary dedication. In fact, given the low wages that teachers are generally paid, we must be able to use teachers of average intelligence and dedication to carry out the majority of our educational goals. Science suggests that there are methods which, when applied correctly, should give us a desired result. *Writing in Biology*, taught using the formula presented here, is an attempt to allow the students to learn their needed skills in a learning environment that is optimized for their success. Since the majority of work expended in the learning process is by the student, we should be able to design and apply a teaching methodology which allows the students to learn at an optimal rate. We become engineers of the learning process, applying good organizational skills to keep the learning environment well stocked with the correct learning tools and opportunities for our students. This may be a big difference from how we originally envisioned passing on our interests to our students (overwhelming them with our intellect), but we must come to the realization that the old forced feeding approach has not been working well and a new direction is called for. Using the formula provided here, we use the old trick of convincing the student that their learning was their own idea. I know that I learn best that way.

The future for any course should include experimentation with new features. Given the importance of IT and computers in modern society and the recent development of Learning Goals by the Biology Department which include teaching more math skills [15], I am experimenting with adding a project or exercise to the *Writing in Biology* course which uses the new, free, computer programming language, J [16]. I am hoping that it would at least be useful to give our students a taste of what using a modern computer language is like and give them a chance to learn how to communicate with or to their own computer.

Application of this Model to Other Courses

Aspects of the *Writing in Biology* model as taught by me certainly could be extended to sections taught by other biology instructors as well as Junior Writing Program courses taught in other science disciplines. Many of the techniques and problems described are not in any way limited to the discipline of biology. In fact, a collaboration of several science faculties teaching the Junior Writing Program course might benefit from consolidation of effort and sharing of resources.

Application of this model to teaching of other subjects is under development by this author. One obvious application is to a laboratory course that is also inherently project- and group-based. Combining the Technical Report and the Poster/Talk projects into the traditional lab report aspect of a laboratory course are natural progressions that are under way. Insertion of ad hoc assignments would improve lab group member tardiness and absences. Given the usual time constraints in labs, some aspects of group organizational improvements in e-mail communication could make the laboratory experience more positive for students. Clearly, the benefits of having all protocols and informative hyperlinks organized within a course website is applicable to any laboratory course. ■

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Bio

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EXAMINATION OF STUDENT-ACTIVE LEARNING PRACTICES IN A COLLEGE/MIDDLE SCHOOL EDUCATIONAL COLLABORATION

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A college and middle school student teaching collaboration was developed to interest more college students in teaching K-12 science, to enhance diversity among K-16 teaching faculties, and to inspire the K-12 students to expand their knowledge beyond their classroom curriculum. To assess our results, we used a modified Likert survey instrument and self-reflective analysis in middle school and college students, respectively. Overall, middle school students expressed satisfaction in the science learning in which they participated. In addition, college students reported that they learned specific content when made responsible for teaching material to younger students. Collaborative projects such as this one may positively impact attitudes towards math and science learning among middle school students. Research suggests that middle school girls who have positive experiences in math and science classes select further training and career options in these areas. Similarly, college students reported increased interest in K-12 teaching. Collaborative project based learning could be successfully modified by other educators for use in alternative or mainstream educational settings.

Introduction

The identification, study, and education of gifted and talented students have progressed to become more inclusive over time. Gifted and talented students are those who exhibit marked intellectual ability, control and commitment, all of which may be modified by individual subjective experience [1,2,3]. Gifted and talented individuals have traditionally been less likely to be identified in minority populations and/or in lower income populations [2,4]. Institutional teaching strategies combining gifted and talented special education has included both heterogeneous (mixed ability and inclusion) and homogeneous (peer grouping educational interactions) groups, depending on curricular goals, individual plans, and community educational philosophies [1,5], any of which may influence academic progress.

One of the common myths associated with gifted students is that they can succeed on their own. In reality, they need guidance to help them develop their potential. One way in which students come to view learning as important and share its excitement is by exploring new experiences. Working across disciplines provides a way of exploring new areas while providing a familiar framework that may allow some students to relate knowledge to more comfortable and familiar topics. Creative tasks are considered to be useful when working with gifted students for whom this capacity has been thought to be particularly well developed [1,6]. It has also been suggested that college students more easily develop structured knowledge capacities when they are active, collaborative constructors of their own process of learning; ultimately, such activities may change scientific practices [7]. Inquiry-based teaching practices vary between institutions and individuals, but typically include the following features: 1) students are involved in complex, realistic problems; 2) students gather, analyze, and interpret their own data, learning technical and cognitive skills, attitudes, and intellectual maturity through this process; 3) students are asked to reflect on their own individual learning processes; and, 4) students begin to understand the benefits and constraints of scientific and mathematical practices as they construct knowledge in a given area [7].

Accordingly, college students from three undergraduate natural and cognitive sciences college classes visited and team taught, using active project participation, middle school gifted and talented students in sixth, seventh, and eighth grade classes over the course of eighteen months. The effect of this intervention was evaluated using qualitative data obtained from short questionnaires administered to the middle school students and from self-reflective commentary from collegiate students following their participation in the teaching exercises and at the conclusion of the college courses. This collaboration was a way to interest more college students in teaching K-12 science, to engage the college and middle school students more in their own learning, and to assist in fulfilling the stated goals of the Science, Technology, Engineering, and Mathematics Teaching Education Collaborative (STEMTEC) program. Those goals included the following items: 1) to increase the numbers of undergraduate liberal arts students who consider teaching as a potential career; 2) to facilitate representation of minority students among those who might consider science, mathematics and education careers; 3) to gain exposure of college and university faculty to teaching practices commonly implemented within the context of K-12 education; and, 4) to address content curricular framework requirements mandated by recent Massachusetts Board of Education Educational Reform legislation and their effect on K-12 classrooms.

Institutional Characteristics

Undergraduate institution: College students participating in this collaboration were drawn from a selective baccalaureate–granting private liberal arts college that features a multidisciplinary curriculum and emphasizes nontraditional modes of instruction and student evaluation. Students participating in this collaboration were predominantly female and were white, with the exception of one African-American male matriculant, and were early in their academic career (Table 1).

Middle School institution: Middle school students who participated in this collaboration came from one of two middle schools in a city of 56,000 residents. This school educates 1,050 students equally distributed among grades 6, 7, and 8. Nearly half of the diverse student body qualifies for free or reduced lunch (40.1% free, 8.6% reduced). The ethnic composition of the students is: 75% White, 20% Hispanic, 3.4% Black, 1.5% Asian/Pacific Island, and .5% American Indian/Alaskan. The primary languages of the students are: 84.1% English; 11.2% Spanish; 2.3% Russian; 1.5% Polish; .2% Portuguese; and Chinese, Greek, Italian, Ukranian, Vietnamese, and Urdu at .1% each.

The middle school students who interacted with the college students in this study came from Bellamy's Resources for Enrichment and Advancement in Chicopee (REACH) Program. The REACH course curriculum revolves around interdisciplinary problem-solving activities with the major topics changing several times a year (Table 1). Different topics are selected on a yearly basis. Students must demonstrate that they possess, and are willing to use, advanced academic talents to qualify for this program. Approximately 6% of the school's student population participates in the REACH program. Based on Renzulli's model of giftedness, REACH students must show potential through above-average intelligence, creativity, and task commitment. These characteristics are determined by a combination of scores on national achievement tests (such as IOWA, CAT) in reading comprehension and math concepts, teacher/parent/student recommendation, a cognitive skills index, and report card grades. REACH students meet in small groups (up to fifteen students) consisting only of gifted and talented student classmates for 45 minutes daily, and then spend the remainder of the school day with other middle school students as members of their more traditional classes. Participation in the program is optional for the invited sixth, seventh, and eighth grade students.

Structure of the Collaboration

Prior to the beginning of the first collaborative series, the authors met several times to plan and coordinate discussion topics and to determine specific evaluative goals and methods for each class. In addition, specific collaborative topics were selected by the authors to serve as study and teaching topics for both middle school and undergraduate student participants, within the overall context of each respective course or curriculum. The topics were chosen to complement course or module content curricular goals within each student group (Table 1). As this was the first time that this type of collaboration had been developed between these two institutions, there were also individual visits made to each respective institution by each faculty member prior to the start of the academic year. These visits served to confirm scheduling details and to provide assurance of administrative support for implementing this collaboration.

Experience # 1: First and second year undergraduate college student participants were matriculants in three courses. The first course was an interdisciplinary, 100-level introductory course entitled, *Animals in Human Societies: Relationships, Bioethics, and Welfare* which examined the role of animals in Western and non-Western human societies through their literary, spiritual, artistic, and scientific representations. Each college student was required to work in a small teaching group (chosen based on topical interest, and in the case of very popular topics, by lottery) to develop a project, presentation or actual experiment that would involve the middle school students in inquiry-based activity. The overall goals of this seminar were to introduce early college students to selected scientific areas using an interdisciplinary approach and to foster improved communication and scientific literacy. College student goals were varied and included interest in learning more about selected subjects, to fulfill a desire to become engaged in pre-professional curriculum prerequisite, and to complete college-wide science distribution requirements. Many of the student matriculants in this course were not planning to major or concentrate in a scientific discipline.

College student teaching groups focused on the ocean, and specifically, the role of animals in human activities that might be associated with marine or aquatic environments. The topic assignments that the college students developed are listed in Table 1 and included: 1) Physical sciences - pH Laboratory, in which college students conducted a self-designed, in-class experiment with middle school students using a pH meter to examine predicted and actual pH values among different water sources, such as pond water, rain water, and tap water from the middle school classroom; 2) Health and Medicine - ocean-based substances and foods used to maintain human health or conversely could have been disturbed by environmental pollution; 3) Animal Communication - classical great ape studies of sign language and communication, and dolphin cognition and communication, whereby small groups of middle school students also tested their non-verbal communication skills by finding alternative ways to convey a concept or object among their group members; and, 4) Humanities, Arts and Political - a project with the specific goal of providing information that might allow the younger students to formulate an opinion about several potentially controversial and interesting topics. This student teaching group, the most interdisciplinary of the series, focused on the presence and representation of oceanic animals through the writings of Rachel Carson, followed by playing examples of humpbacked whale song. They also discussed concepts of animal welfare versus animal rights through examples such as the benefits and consequences of maintaining captive animal populations in aquariums and zoos and contrasting veganism/vegetarianism with animal product use and consumption. Animal political representations were depicted through the use of cartoon images and in political symbolism, such as the Democratic and Republican parties. Middle school students participated by drawing an animal or a species with special significance to them and that might be similarly represented in prose, sound or writing, or politics.

The college class focus on marine biology/oceanography paralleled the first gifted and talented middle school curricular module, "Under the Sea." Middle school students participated in a variety of activities to enhance their research of this topic. They designed two-dimensional models of various sea life to surround them in the classroom. The students in eighth grade created a coral reef that covered the entire back wall of the classroom. One seventh grade class specialized in large sea creatures (such as whales and dolphins), which graced the side walls. The other seventh grade class researched deep-sea creatures, which covered the front of the room. The sixth graders each chose a specific fish and produced a three-dimensional model, which hung from the ceiling. The head of an aquarium company held a special assembly for the REACH students so they could experience different types of sea life including samples of shells, coral, the skeleton of a blowfish, and a preserved sand shark. Similarly, the state police diving team also brought their equipment so students could see how rescues are made in water.

Informal learning opportunities were also made available to the middle school students and were financially supported by this collaboration. Middle school student classes visited Hampshire College and participated in an on-campus college introductory, problem-based learning class. They toured the campus, participated in a college level problem–based learning problem, discussed college preparation with the director of admissions, and visited the Pratt Museum of Amherst College, where they were engaged in a natural history "puzzle" hunt. In the middle school classroom, a marine aquarium that was stocked with several marine fish species and maintained by a professional marine aquarium service was also supported through this collaboration. Its presence became an additional focus of the "Under the Sea" module that the middle school students completed, added a living component with opportunities for observation, analysis, and data collection in marine science, and illustrated the habitat and marine ecosystem that the middle school students were concurrently studying. Pre- and post-field trip evaluations were obtained by the middle school faculty member from the middle school students who visited the campuses, many of whom had never been on a college campus prior to this visit.

Collegiate groups in the first teaching series met outside of class times to develop their project with the support of a student peer facilitator who was also matriculated in the class. This student was a more advanced student class participant: she had completed all major distribution requirements and had proceeded into her major field of study. STEMTEC programmatic funding support provided stipend and expense monies; the peer mentor student usually provided transportation for herself, and college study group members. College students visited the middle school classroom once and gave presentations and/or led exercises for two successive middle school classes (Table 1). The college student presenters, and both faculty members, had a brief classroom meeting to discuss the experience with them at the conclusion of each session. This was followed by a longer meeting in which the students, peer facilitator, and college faculty member reviewed the experience with college participants and discussed their perceptions of the presentation experience and preparation period, in conveying interest and information to middle school students in a format that they could understand, and in the overall teaching experience. In addition, each college student group made formal midterm poster presentations of their experiences in the classroom for their classmates and the middle school faculty member.

These presentations were also evaluated as a component of each college student's individual academic class evaluation portfolio, a standard institutional method of evaluation in lieu of grade assignment. Students were evaluated by the college faculty member for teaching projects, using the following criteria: originality of presentation; knowledge content and literature cited; analysis, integration, and communication of scientific and interdisciplinary knowledge; and, their ability to interact with middle school students in an active way. The middle school faculty member provided additional insight about their activities within the classroom, but was not responsible for an overall academic evaluation for the undergraduate students. The college student who served as a peer facilitator was also evaluated as a course matriculant; both faculty members in the collaboration evaluated her activities as peer facilitator.

College students had the opportunity to comment anonymously on their experiences in the classroom as a part of their overall class evaluation at the end of the semester. They were also able to convey their thoughts as a component of their self-reflective goal-setting assessment essay that was submitted as a part of the course portfolio. To assess the effect of these sessions on the attitudes that middle school students held towards science and college student teaching sessions, a short survey was developed by the middle school faculty member and was administered to the middle school students participating in the first series of college student teaching visits. This survey asked them to indicate what items they learned, what they liked and disliked in the college student presentations, and provided a space for free writing of any additional comments that they might wish to make. Generally, middle school students received the surveys within one week of their college student teaching experience and completed them during a classroom period.

Experience # 2: Based on comments obtained from undergraduate students in their post-presentation meetings and self reflective portfolio essays, and from middle school students through informal surveys given after each teaching project in the Teaching Experience # 1, the second and third series of college student class visit procedures and schedules were modified (Table 1). First year and transfer college students were drawn from a Natural and Cognitive Sciences course, *The Neurobiology of Learning and Memory*, a seminar and laboratory course whose goal was to understand and develop expertise in the biological mechanisms underlying learning and memory in vertebrates through study of texts and primary journal articles. College students worked with sixth grade middle school students who were very interested in finding out more about how people and animals learn. Middle school students participated in the collaboration as part of the regularly scheduled class. College student participants were volunteers and their performance in this area was incorporated into their course evaluation. In their presentations, two groups of college students ran experiments using two animal behavioral assays in class with middle school students. The college students also presented data from their own experiments using these assays to the middle school students. A representative of the second student group ran the Weschler Digit Span Memory Test, a standard psychological instrument used to assess human memory and cognitive function, with middle school student participation. Each middle school student group had an opportunity to experience both types of learning experiments. Student feedback and assessment was performed for each group as previously discussed with the following modification: middle school students received a modified formal formative assessment survey instrument, Science Laboratory Environment

Inventory (SLEI) [8] (Figure 1) to determine the effect of this intervention on their view of science learning. In a manner similar to those held at the conclusion of each first series visit, there was a meeting in which college students participating in the study discussed their perceptions with us of the experience that they had just had in preparing the material, conveying their thoughts, and working with the middle school students, and their overall teaching experience.

Experience # 3: A single, afterschool workshop was developed by college student volunteers featuring active field investigation of environmental microbiology in samples collected on the middle school campus. College students were matriculants in a first year course, *Cellular Pathology: Bacteria and Viruses*, which consisted of a classroom and laboratory format. Most students were in the second semester of their first collegiate year. The focal areas studied in this course were: 1) Environmental microbiology, featuring an individually designed laboratory project examining differences in microbial flora between varied sites on the Hampshire College campus; 2) Food-borne enteric and neural diseases which focused on significant diseases such as E. coli enteritis, Salmonellosis and Listeriosis, with a second investigative student project; and, 3) Retrovirology, with special emphasis on human immunodeficiency virus, feline immunodeficiency virus, and simian immunodeficiency virus as animal models of infectious disease, and including examination of the secondary complications of these diseases. Middle school students were drawn from a single middle school classroom module, *Introduction of Microbiology*, and consisted of sixth through eighth grade gifted and talented children. Participation in the middle school afterschool workshop was voluntary for both college and middle school student populations.

The college students developed a workshop module that paralleled their experiences in the laboratory and field. After personal introductions, the college students gave a scientific poster presentation to the middle school workshop class illustrating their group work on each respective project that was performed on the college campus. They also showed middle school students bacterial specimens on culture plates originating from college laboratory experiments that had been used to identify previously not well-characterized environmental bacterial samples. College student teachers also demonstrated how the plates were streaked with bacteria and examined glass slides containing fixed, Gram-stained bacterial specimens while explaining differences between Gram-negative and Gram-positive bacteria. Environmental sampling and differential staining of local soil and water sites at the middle school was then executed as a group led by the college students. The middle school students rotated through individual stations in the classroom that allowed them to process their samples, fix, stain, and observe bacterial populations on microscope slides using a hand-held microscope, and more closely, using video light microscopy. At the conclusion of the afterschool workshop, the college students met with the middle school and college faculty members to discuss their experiences and to give feedback for future workshop development of this type. College students were evaluated as noted earlier, while middle school students were queried by the middle school faculty member in subsequent classes to determine their attitude, and enthusiasm, towards science learning stemming from their involvement in the workshop.

Collegiate Outcomes

Experience # 1: Most college students participating in the teaching exercises met all course expectations, and their own varied goals in matriculating into the class. Most also completed Division I examinations in Natural Sciences, a prerequisite to advancing through the Hampshire College academic program. Several college students expressed increased interest in teaching as a career and felt that their participation in this experience facilitated their exposure to the field. All students reported that they understood the content that they presented, and that they had greater ease of scientific communication.

Experience # 2: There were fewer college students participating in the second teaching series. Eligible student volunteers also completed Division I examinations in Cognitive Science. Decreased participation may be attributed to the voluntary status of the teaching project, which required additional time, intellectual effort, and travel. All participating students provided commentary that they were more effective learners once they became responsible for conveying information to middle school students.

Experience # 3: Participation in the third teaching experience, an afterschool workshop, also assisted students in completing their Division I examination in Natural Science. This experience also appeared to increase their experience in leading field and laboratory experiments.

Overall, collegiate students reported that they had fun teaching in the middle school classroom. They were impressed by the energy, attentiveness, and range of questions that they received from the younger students, and their previous experience in independent project execution gained through their participation in the REACH program. Some of the first-year undergraduate students reported that it was difficult for them to gather, and condense, their topic information into a format that could be easily conveyed to their audience. In some cases, their presentation was the first time that they had had an opportunity to present to a large group of students since beginning their undergraduate education. However, college students were impressed with how much better they felt that they had learned the teaching presentation material. They attributed this outcome to discussing it with other group members, interpreting data and associated information, and communicating to a group of middle school students concepts and attitudes that college students thought might be difficult to understand. While there was no attempt to specifically teach students "how" to teach, our goal was to provide opportunities for college and middle school students to learn using active collaboration, and to generate enthusiasm about science in an educational setting. Based on comments from these college students, it seems that these goals were achieved. In their final class evaluations, students in all teaching experiences commented that the experience of working in groups, and teaching the middle school students, was one of the highlights of their semester in the class.

Middle School Outcomes

Experience # 1: Middle school students enjoyed having college students come into their classrooms, and they became excited about learning scientific and interdisciplinary concepts. Their experiences may provide an initial exposure to college as an education goal for some middle school students who may have been socioeconomically disadvantaged or have experienced home environments where family members had limited educational background and opportunities. We also observed that middle school gifted and talented students participating in this teaching series experienced enhanced self-esteem and goal setting, realizing that it may be "ok" to be "smart" as a way of demonstrating interest and intelligence among a peer group. This may be particularly important in school settings where gifted and talented students progress through academic programs in classes with student peers of widely varying intellect and ability.

Experience # 2, 3: Middle school students were introduced to the behavioral sciences and to concepts of humane handling and care of animals in laboratory and field experiments, with the realization that advancing knowledge in this area benefits all species. The SLEI questionnaire responses suggested that middle school sixth grade students were enthusiastic about the presence of college student teachers. Eighty percent (8/10 students) of middle school students chose a highly positive response to the statement, "I enjoy working with older students."

Most students (9/10 students) most enjoyed working with animal behavior and maze testing. The one student who preferred the Weschler Digit Span Memory Test also noted that it was sometimes harder for her to memorize numbers with distractions, but that she wanted to have more time to pursue the "memory game" with the college students. When queried, middle school students requested additional animal studies, picture games, and other experiments. Afterschool workshop participants also had a robust and positive experience, featuring guided field experience, and direct comparison of their data to that obtained earlier by college students.

There were few areas in the presentations that the students disliked or commented on. In most cases, comments addressed sentence syntax or structure, and indicated that they should be easier for them to understand the questions for which they were being asked to provide a response. Younger middle school students had a more difficult time providing in-depth responses to the instrument, and questions were answered more superficially.

Specific middle school student comments were as follows:

- "I learned about how different people, religions, cultures, and countries view animals";
- " I liked listening to the whale sounds on the tape";
- " I learned a lot about Hinduism and about Sea World and caged animals";
- "[I learned] the relationship between real life animals and characters";
- " I learned about how animals can be represented by artistic symbolism. I also learned that there are many books written about animals...because I thought that it was interesting. I never realized before that animals can be so important to so many people in other countries, and I thin(k) that we take for granted how good we have it and don't really realize how we a(re) hurting the animals and their environment";
- " I learned their are many different kinds of pollutants, and that it could make a big difference just to recycle one thing";
- " Since I already knew about the communicating chimpanzees, I learned a lot about the dolphins. I learned how they used echo-location to find their way around the ocean. I find it also pretty amazing how they can point out objects to one another efficiently [without verbal communication]... I liked how they had a little experiment ready to give us an idea of how dolphins describe objects."

Overall, there were very few items that the middle school students disliked; there were critical comments about the amount of time that the college students were available (too short), their physical appearance in some instances, about some hands-on activities that they did not enjoy, such as drawing, or about not having enough hands-on activity in the presentation.

Discussion

There were several benefits of this collaboration. Middle school students benefited by learning directly about undergraduate study. The college students who worked with middle school students were interested in them, and this attitude and positive interaction might help middle school students who were involved in the project to view college education in a positive light. Having the benefit of student teachers that were closer to their age may be important as a means of making education seem more attainable. Participating in a "cool" project that involved college students was also a positive social motivating factor among middle school students. This is an especially important factor in the socialization of gifted and talented students who sometimes must project an effect that de-emphasizes their natural attributes if they are not congruent with the values of the environment in which they live and study [3]. Cooperative learning also reinforces self-esteem in a positive fashion for these students [4,5,9,10,11]. Finally, middle school students had an opportunity to perform experiments, create knowledge, formulate opinions, and critically evaluate their view about potentially controversial topics [1,4,6,7,12-15]. These types of activities may be especially important in educating middle school girls [9,10,15-19]. Previous studies have documented that using problem solving science inquiry coupled with positive social experiences in math and sciences have a long lasting impact [15,17,18,19]. Further, future course selection, continued participation in science and mathematics education, and selection of careers in these areas by adult women are positively affected by experiences in this middle school developmental period. It is possible that other students will also gain from exposure to these types of experiences.

College students were able to work in groups and create experimental approaches to illustrate topical areas of interest. They also experienced the cognitive, and experiential, effort involved in teaching. An emphasis using inquiry–based pedagogy that involves students as being responsible, active constructors of their own learning has been shown to be effective in educating community and liberal arts college students [7,12]. Students also benefited by working with middle school students in that they received significant support and positive feedback from their work from these younger students.

Producing a developmental–, age–, and grade–appropriate assessment instrument or rubric for evaluating changes in student content knowledge that would reflect this type of intervention would be helpful in assessing this type of collaboration. The SLEI was originally developed to assess student cohesiveness, open-endedness, integration, rule clarity, and material environment in high school biology students [8], and could be further adjusted or replaced with another instrument to more precisely assess student academic progress. Cost recovery for anticipated expenses is crucial. The challenges that we experienced in developing this series of collaborative teaching experiences involved the following: 1) incorporating middle school block scheduling and transportation into college class scheduling periods, and maintaining commitment from college students to perform additional independent work outside of class contact hours; 2) obtaining funding and transportation for middle school student trips to college campuses, as well as college student and equipment transportation to the middle school; 3) developing administrative support, such as obtaining a bus and driver, parent volunteers, food for students on the trip, and provision of substitute teaching staffing for middle school faculty, with appropriate release and insurance form signature; and, 4) maintaining informed consent, with parental knowledge of this program, as well as a restriction on information technology use among students whom are minors.

Advance planning to serve curricular and content-specific course requirements for undergraduate faculty, and state-mandated curricular requirements for middle school faculty, are important and will assist in developing a fluid, interlocking teaching and learning experience for the respective student populations. Curricular change and implementation is not always easily anticipated, or accepted, by students or faculty. In Massachusetts, educational reform has resulted in the development of testing strategies, such as the Massachusetts Comprehensive Assessment System (MCAS), and curricular frameworks that require exposure of middle school students to proscribed content areas [13,14], which may occur at the expense of opportunities to engage in unstructured time or creative enterprise. MCAS testing will determine whether students graduate from the public educational system. Testing may also modify the extent of student preparation for further academic study. While standardized testing pressure is in many cases lessened on college campuses, there are still important areas of knowledge and content students need to know. However, there is more flexibility in developing means to address both content, and process of learning in college and in this particular institution. It may also be that college students participating in alternative, nontraditional classes are better able to integrate interdisciplinary content areas as a consequence of the emphases specific to this style of education. Inquiry of this type may benefit learners of all abilities and could be implemented in mainstream educational settings and student populations.

Conclusion

This was a positive experience for middle school and college students who were engaged in this project. Involvement of nontraditional college students and gifted and talented middle school students provided a unique setting in which to develop this initial project. One future goal is to introduce further refinements to allow comparative and quantitative analysis of educational outcomes. A collaboration of this kind may also be used as one component of a curricular program to address state and national educational learning standards [13,14]. These standards include "common core" breadth requirements spanning science, mathematics, and the humanities; science inquiry methods (making observations, generating a study question, gathering data using complex tools, analyzing results, communicating scientific ideas and demonstrating knowledge and understanding); and, specific subject content, such as microbiology, organ systems, population and ecosystems, and others. As a result of our experience, we anticipate that other educators in many different educational settings could successfully modify this form of project-based learning for use in their own classes. ■

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Bios

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TABLE 1: A SUMMARY OF TEACHING COLLABORATIVE PROJECT ORGANIZATION

ORGANIZATIONAL VARIABLES	*TEACHING EXPERIENCE # 1*	*TEACHING EXPERIENCE # 2*	*TEACHING EXPERIENCE # 3*
College Subject	Marine Biology & Aquatic Habitat/Environmental Science	Neurobiology: Learning and Memory	Cell Pathology: Bacteria and Viruses
# College Students	16 / 16 total matriculants; Required Participation	4 / 7 total matriculants; Voluntary Participation	3 / 3 total matriculants; Voluntary Participation
Middle School Subject Content	Under the Sea	How Learning Occurs	Genetic Engineering
# Middle School Students	20 students; 8th grade only	13 students; 6th grade only	13 students; 6th, 7th ,and 8th grade
Overall Theme & Organization	Exploring Human & Animal relationships in Aquatic Environments *Teaching Group visits to MS:* 1: Animal Communication 2: Health and Medicine 3: Physical Sciences - pH 4: Humanities/Arts/ Politics	Memory Testing *Teaching Group visits to MS:* 1: Introductions 2: Experimental visit a: Maze testing b: Weschler test	Environmental Microbiology *Teaching Group visit to MS:* 1:Afterschool Group a: Introductions b: Poster Talks c: Field & wet lab
Student Peer Facilitator Present	Yes: Junior Student and class matriculant with completed science distribution requirements	No	No
Middle School Field Trip	Yes: Undergraduate colleges Natural History Museum	No	No
Timing	1998 Fall Semester	1999 Fall Semester	2000 Spring Semester

FIGURE 1

MODIFIED SCIENCE LABORATORY ENVIRONMENT INVENTORY (SLEI) ASSESSMENT TEST

Name________________________ Class________________________ Date____________________

	Almost Never	Seldom	Sometimes	Often	Very Often
1. I get on well with students in this class.					
2. I can follow my own interests in class.					
3. My class has clear rules to guide my activities.					
4. I can develop my own rules to guide my activities.					
5. I have little chance to get to know other students in this class.					
6. I am required to solve a given problem by myself.					
7. My class is informal.					
8. My classmates and I work together to solve problems.					
9. Our problems are important to other people.					
10. I can depend on other students for help during my class.					
11. I work cooperatively in classroom sessions.					
12. I decide the best way to proceed during class problem-solving sessions.					
13. My problem–solving work is related to my ideas about science and technology.					
14. I enjoy working with older students.					
15. I feel that I have learned about science and mathematics through my work with college students.					
16. Working with college students helped me to learn more about science and/or mathematics.					
17. I can use what I learned from college students about science, technology, and mathematics outside of my classes.					

Short Answer Questions:

18. The topic that we studied that I enjoyed the most was:

19. The topic that we studied that I enjoyed the least was:

20. What did you learn from working with the college students?

21. Can you describe what you did together with the other students?

22. What would you like to have more time to do with the college students?

23. Do you have any suggestions for future activities?

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THE STCC SCIENCE TEACHING INTERN PROJECT

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The Springfield Technical Community College (STCC) Science Teaching Intern Project was implemented as a pilot study to give community college students an opportunity to experience science teaching. At the same time, it provided seventh graders in inner city middle schools opportunities to interact with college students and to take advantage of science resources not usually available to them. Interns attended weekly meetings and participated in an all-day science field trip at the college. Most participants also made observations in a middle school science classroom and presented a science activity in the classroom. Not only did the project provide a partnership between STCC and two Springfield public schools, but it also involved interaction with the University of Massachusetts School of Education, since a doctoral candidate provided expertise in education methodology and in evaluation of the project. The project was evaluated by the interns, the two K-12 teachers, the seventh graders, and by the doctoral candidate. There was clear enthusiasm for the project provided by all the sources. The conversion of this project into a one-credit course is currently under development.

Introduction

It appears that the science community often does not place serious value on science teaching. According to K. Davis, positions outside of the traditional academic research setting are not valued and are often considered "dead-end jobs" occupied by "science drop-outs."[1] At the same time, science teacher shortages commonly lead to the assignment of middle school teachers and high school teachers to inappropriate subject areas [2]. Therefore, undergraduate science students do not often get a positive view of K-12 teaching from science faculty but there is still a great need for science teachers who are well trained in their disciplines. To help fill this growing need, it seems possible that exposing undergraduate science students to teaching opportunities might increase the likelihood that a teaching career will be pursued. The Springfield Technical Community College (STCC) Science Teaching Interns Project was devised as a means to test this idea by exposing students enrolled in biology courses at STCC to teaching opportunities. In addition, discussions on teaching methodology and peer-group interactions were provided. There were two different types of teaching experiences: one in a middle school classroom and the other at a field trip day at STCC. The teaching interns in the program were required to attend weekly meetings. To be certain that the interns participating in the project had an adequate knowledge base, they had to have completed at least an introductory biology course.

Brenda Capobianco was asked to serve as a consultant for the project. Not only is she a knowledgeable doctoral candidate, but she is also a fourteen-year veteran teacher. She gave a presentation to the interns on what to expect during classroom visitation and on how to prepare for "teaching" an activity. She also helped with the evaluation of the project. At the interns' request, she was present for the field trip day at STCC to evaluate the teaching activities.

Description of the Project

The STCC Science Teaching Intern Project was developed during Fall 1998 for implementation in the Spring 1999 Semester. A preliminary proposal was presented to the science coordinator of the Springfield Public School Department. She was enthusiastic and with her help, two seventh grade teachers in two different middle schools were recruited to participate and to provide teaching expertise for the teaching interns.

Most of the interns observed a middle school seventh grade science class taught by one of the participating teachers. They also had an opportunity, under the supervision of the teacher, to present an activity or lesson to the same class. In addition to the teaching activities, the interns in the program were required to attend weekly meetings. These meetings were used to prepare for both observation visits and "teaching" visits to the middle schools, as well as the STCC field trip portion of the project. One week they viewed and critiqued a video of classroom teaching by a number of practice teachers. Another time, Brenda Capobianco was a guest presenter. Several meetings included the two middle school teachers who were involved in the project. The interns seemed genuinely glad to get together each week and they were certainly supportive of one another.

At the end of the semester, the two participating teachers and their classes, a total of about fifty seventh graders, were invited for an all-day field trip to the Department of Biological Sciences at STCC. The interns organized four 50-minute activities for the day. Two activities were prepared by just one intern, and two were prepared by a pair of interns. These activities were presented four different times throughout the day in order for the guests to experience all four activities. The activities included, "The Invisible World," "Exploration into Galls," "A Look at Genetic Engineering," and a "Nature Study." Each planned activity was reviewed in detail with the teachers. In addition to the four activities, visiting seventh graders were treated to pizza for lunch and a discussion/evaluation period at the end of the day. When the seventh graders were gone, the interns spent time reflecting on the day and receiving constructive suggestions and praise from the evaluator.

Project evaluation was provided several different ways. The teaching interns completed questionnaires at the beginning and after completion of the project. They also shared their views freely with the evaluator. The two K-12 teachers each wrote some comments shortly after the field trip to STCC. At the end of the field trip day, the seventh graders were asked to write three things they learned, two things that surprised them and one remaining question. They also participated in a group discussion with other students and one of the interns. Finally, the evaluator provided comments on the project.

Project Evaluation and Analysis

An intern questionnaire was administered on the first formal meeting day to learn about the interns' attitudes toward science and toward teaching as a possible career choice. Table 1 shows the specific questions, both individual and overall averages for each question and the average score for each student. It should be noted that one question, number 5, is written as a negative question.

Table 1 Intern questionnaire to determine intern attitude to science and to teaching. A "1" indicates strong agreement with the question and a "5" indicates strong disagreement with the question.

Question	Intern 1	Intern 2	Intern 3	Intern 4	Intern 5	Intern 6	Overall Average
1. I enjoy doing science experiments.	2	1	1	1	1	1	1.2
2. I can solve problems.	2	3	1	2	2	1	1.8
3. What I am learning in science will be useful to me outside of school.	2	1	1	1	2	1	1.3
4. I think about things I learn in science class when I'm not in school.	1	1	1	1	1	1	1.0
5. I do not want to take anymore science classes than I have to take.	4	5	5	5	3	5	4.5
6. Reading science is more fun than it used to be.	3	1	1	1	2	1	1.5
7. I enjoy working with children.	1	1	2	2	1	1	1.8
8. I am likely to pursue teaching as a career.	1	2	3	2	3	1	2.0
9. I am looking forward to working with a middle school teacher.	1	1	2	2	1	1	1.3
10. I feel confident about going out to a middle school.	2	1	2	2	1	1	1.5

Average score of the ten items for each intern after converting question 5 responses to a positive statement format.

Intern 1	Intern 2	Intern 3	Intern 4	Intern 5	Intern 6
1.7	1.3	1.5	1.5	1.7	1.0

Analysis: The six interns appear to vary little in their average scores for the ten questions. It is clear that they all enjoy science and feel enthusiastic about being able to interact with the seventh graders. With the exception of two individual responses, it can be said that the interns agreed (often strongly) with the statements related to science attitude. Two interns indicated that they were undecided about the likelihood of pursuing a teaching career. The other four were likely to pursue teaching as a career. Average scores of 1-1.7 indicate that the interns had a positive attitude about science and teaching. It should be pointed out that question 5 was the only question which was written in a negative question format and therefore, a score of "5" actually indicated a strong desire to take more science courses. Before computing the average score of the ten items for each student, question 5 responses were converted to a positive statement format.

A teaching experience questionnaire was completed by the teaching-interns during the discussion period that followed the field trip at STCC. The purpose of the questionnaire was to obtain personal demographic information as well as final views on the project. The questions that followed the demographic information section allowed for open-ended responses.

Six interns participated in the project, five females and one male. Half of the participants identified themselves as White (Non-Hispanic) while the others described themselves as African-American, Native American, or "Other." The group, on average, was between 25 to 34 years of age. All but one of the students were full-time and had declared a major at STCC.

Interns reported peer support as positive, constructive, and informative.

> "They were great! I learned so much from our constructive criticism and interactions."

> "I enjoyed observing their different styles of teaching."

Teaching interns stated their interactions with the middle school teachers were resourceful, informative, and helpful. The teachers served as good role models and provided structure to individual lessons and ideas. The experience for some students allowed them to acquire a greater appreciation for and awareness of teachers and their abilities.

> "She was consistent and displayed good skills in how she was able to get the attention needed from her students."

> "Teachers are SAINTS!...Teaching is a huge job."

Interns were also appreciative of the project coordinator's work and involvement in the project. They found her to be supportive and appreciated her patience, flexibility, and guidance. They attributed the success of their own experiences to her efforts in making the program a productive one. One student indicated communication problems due to busy schedules.

> "She fed us, she fed us pieces of education - she put us in touch with great people."

> "She was very patient and supportive."

In addition, the interns were all extremely enthusiastic about the participation of the evaluator/guest presenter. They felt that she provided them with useful techniques, as well as productive criticism of their teaching.

> "She is a person who I inspire to be. She seems so natural and so positive when talking about the children. I hope I grow to become the kind of teacher she is. I need a mentor and I like her personality best."
>
> "She has a personality that is just so beautiful that she is just a joy to talk to, or just share any situation you may have."

The interns made a number of suggestions for improving the project for the following year. All but one intern would have preferred credit towards graduation to a stipend. There was a general sentiment that the project required a lot of work and that starting the project earlier in the year and delaying the field trip experience until several weeks after final exams would have been helpful. Several of the interns desired more interaction with the K-12 teachers.

> "Start a lot earlier in the year."
> "Make this worth a credit towards graduation."
> "Conduct the field trip a couple of weeks after finals."
> "More interactions with teacher."
> "Expose middle school students to classes in different disciplines."

The K-12 teachers were given a fairly open-ended evaluation form on the day of the field trip to send in at their convenience. Sample comments follow.

> "The interns chosen for the project were very knowledgeable, enthusiastic, creative, organized, and excellent candidates for future science teachers."
>
> "It was definitely a pleasure having them observe and teach in my classroom."
>
> 'The only thing I would suggest is to have the interns observe and teach a couple more times before the culminating field trip at STCC."
>
> "This program was a wonderful way to get my students interested in science and scientific careers."
>
> "I feel bad that so few of my students got to experience the excitement and enthusiasm I felt running through my students after the trip."

Both K-12 teachers indicated that they felt the project was a great success and were very enthusiastic about their interactions with the interns. It was suggested that it would be beneficial to have the interns observe and teach more times in the middle schools before the field trip. It was also suggested that it would be nice to involve more than one class of students from each school.

The visiting seventh graders were brought together at the end of the field trip experience into four circles for the purpose of reflecting on the day at STCC through the use of the "3-2-1 exercise." Each circle had one of the interns or a team of interns to facilitate. One of the K-12 teachers joined a circle and the other opted to watch. The students were each given a large index card and asked to write three things they learned, two things that surprised them, and one question that remained. There was a little confusion and some groups produced three surprises and two things they learned. These responses were shared in the circle before they were collected.

> "I hope that you and the other teachers can let us come again. "
>
> "Three things that surprised me today were, glow in the dark bacteria, gall flies only live for two weeks, and the bacteria in the invisible world."
>
> "I learned three things today and they were, DNA is placed in a gel, one maple tree makes 1 fourteen quarts of maple syrup, and there are animals that live two weeks."
>
> "One question I have is ....how they make STCC so beautiful?"

It is clear from the student responses to the 3,2,1 exercise that aspects of all four activities stayed with them throughout the day. Some clearly indicated a desire to visit again.

Brenda Capobianco, evaluator for the project, provided a write-up on the classroom observations she made on the field trip day as well as her observations from the discussion session at the end of the day. Some of her comments appear below.

> "Students conveyed a heightened awareness of and appreciation for teaching. They did not realize the amount of time and energy required to teach one lesson multiple times within a day. They felt proud of their accomplishments and recognized the assistance they received in making it successful."
>
> "When asked, "if you were to do it over again what would you do differently?" most of the students stated that they would talk less, make it more hands-on, and try to answer most student questions. There was a growing awareness of what they were doing when they were teaching."

Analysis: The evaluator felt that the program succeeded in giving the interns an appreciation for teaching. She also indicated that they had gained an understanding of the approach they would take to teaching in the future.

Experiences that Supported the Project Goals

The goals of the project were listed in the original proposal, which was presented to the Springfield School Department. Project experiences have supported all of these goals. Table 3 lists both the original project goals and the experiences that supported these goals.

Table 2 Project goals and experiences which supported these goals

Goal 1	**To provide an opportunity for students, enrolled in courses in the STCC Biology Department, to experience interaction with middle school children in an instructional capacity.**
Supporting experiences and observations	▪ "Teaching" an activity in a seventh grade classroom ▪ "Teaching" one of the four activities (four times) on the field trip day
Goal 2	**To expose STCC students to information on teaching middle school-aged children.**
Supporting experiences and observations	▪ Watching and discussing a video showing practice teaching ▪ Guest lecture from Brenda Capobianco ▪ Seventh grade science textbooks and teaching journals were made available ▪ Meetings with K-12 teachers
Goal 3	**To allow STCC students to create meaningful science activities and to be the instructors of the activities.**
Supporting experiences and observations	▪ Interns created their own science activities for both teaching experiences
Goal 4	**To interest talented STCC students in becoming teachers in the future.**
Supporting experiences and observations	▪ It appears that the project reinforced the desire of four of the interns to become teachers and may have influenced one to head in that direction
Goal 5	**To provide middle school children in the Springfield Public School System with science enrichment.**
Supporting experiences and observations	▪ Classroom activities presented by interns ▪ All day field trip to the STCC Biology Department
Goal 6	**To introduce middle school children in the Springfield Public School System to a college campus facilities.**
Supporting experiences and observations	▪ All day field trip to the STCC Biology Department
Goal 7	**To provide STCC students with the opportunity to interact with Springfield public school teachers.**
Supporting experiences and observations	▪ Two meetings at STCC ▪ Classroom observations ▪ Visits to the classroom with the purpose of "teaching" an activity ▪ The field trip to STCC
Goal 8	**To view this project as a pilot for a possible one-credit course, since NSF funding will not always be available.**
Supporting experiences and observations	An application to make this program a one-credit course will be filed with STCC Curriculum Committee

All eight of the original goals of the STCC Science Teaching Intern Project were supported by the experience. It was difficult to assess how successfully Goal 4, "to interest talented STCC students in becoming teachers in the future," was attained. Four of the interns were very committed to pursuing teaching as a career before becoming involved with the project and these four students remained committed at the end of the project. There were two undecided interns. By the end of the project, one of these students was more favorably inclined to teach and the other decided to continue his goal of pursuing a career in biotechnology.

Conclusion

There is very little attempt to integrate a K-12 teaching component into courses in the Department of Biological Sciences at STCC. The STCC Science Teaching Intern Project was designed to provide an opportunity for students, enrolled in various courses in the department, to experience science teaching and perhaps be more inclined to seek a career in teaching in the future. Although it cannot be stated that the program definitely increased the likelihood of future teaching with this small group of students, the evaluation statements from all involved parties were very positive. Statements from the interns such as the two that follow seem to indicate that the experience encouraged interest in teaching.

> "YES! I can do this! I really love getting back more than I put in - and I did! What a great investment, my future and theirs."

> "The kids were wonderful. They opened my eyes to a different world. They are so bright and I can't wait to be more involved with them."

The fact that the project provided multiple levels of connections—middle school teachers and students, community college instructors and students, and the School of Education of a major university—may be somewhat unique. All of these levels were necessary for the success of the project. The opportunity to work with a graduate student/veteran teacher worked well. It proved to be an excellent way of providing methodology and expertise for the STCC students. The opportunity for the interns to interact with classroom teachers gave them a view of real-life teaching. The interactions with the seventh graders was a critical part of the program. The intern questionnaires clearly show the importance of the peer group that the project provided.

This project was undertaken as a pilot study that may lead to a one-credit course for students to explore teaching science. Conversion to a one-credit course is currently under development. ■

Bio

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Brenda Capobianco was invaluable to the success of this project. Not only was she an evaluator, but she also gave a presentation to the interns and served as a mentor to them. She suggested appropriate evaluation methods and then helped analyze the outcomes. Brenda is a doctoral candidate at the University of Massachusetts Amherst School of Education. Elizabeth Harvey from Chestnut Accelerated Middle School and Kevin Flebotte from Duggan Middle School were enthusiastic mentors for the interns. Their commitment to the project was much appreciated. The teaching interns, the two middle school teachers, and the doctoral candidate from the University of Massachusetts all received stipends for their involvement. Funding was provided by the STEMTEC NSF grant (DUE-9653966).

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THE IMPACT OF A NATIONAL SCIENCE FOUNDATION COLLABORATIVE FOR EXCELLENCE IN TEACHER PREPARATION ON AN UNDERGRADUATE CHEMISTRY COURSE FOR NON-CHEMISTRY SCIENCE MAJORS

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In 1999 and 2000 *Chemistry 312: Analytical Chemistry* for non-chemistry science majors (taken in the junior or senior year), was revised as a result of the instructor's involvements in the Center for Excellence in Teacher Preparation project and an NSF equipment grant. Changes included the introduction of a K-12 teaching requirement, more emphasis on co-operative learning and on inquiry-based exercises. These latter two pedagogical practices had more impact on the laboratory activities than on the classroom activities. Students in the laboratory were assigned defined roles in the groups and all groups undertook a three-week research project. Students' responses to the teaching requirement were (with a few exceptions in a class of over forty) positive, and several students identified themselves as future teachers. Responses to the group work associated with the laboratory and several homework exercises were less uniformly positive, with a significant number of students articulating a concern that their grades were compromised by the presence of weaker students in the groups. The grades awarded, the overall percentages and the exam scores of the students were compared for the years 1998, 1999, and 2000. There was a significant improvement in the overall percentages (and the exam scores) between 1998 and 1999, and between 1998 and 2000. Had the thresholds for the awarding of letter grades not been increased for 2000, there would have been 31 A's awarded to the 44 students who completed the course.

Introduction

Chemistry 312: Analytical Chemistry is a one-semester course for non-chemistry science majors. It is populated by a mix of seniors and juniors from several science disciplines, predominantly biochemistry. The detailed breakdown of the student years and majors is given in Table 1. The course is offered every spring, is worth four credits, and consists formally of three (50-minute) lectures and one (4-hour) lab per week. I have taught the course four times: 1992, 1998, 1999, and 2000. In Spring 1996, I taught the lecture section only. There are 35-45 students. I have three to four graduate student TA's to help with the lab sections.

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The National Science Foundation (NSF) Collaborative for Excellence in Teacher Preparation (CETP) based at the University of Massachusetts Amherst is known locally by the acronym STEMTEC (Science, Technology, Engineering, and Mathematics Teacher Education Collaborative). In 1999 and 2000, *Chemistry 312* was revised as a result of (a) my involvement with STEMTEC as a summer (of 1998) cycle II participant, and (b) of the award of an NSF Instrumentation and Laboratory Improvement (ILI) grant for $60,000 (with an institutional match of $60,000). This ILI award provided funds to buy equipment as part of a program of revision of all of the undergraduate analytical chemistry laboratory courses (there are two other one-semester courses with labs: *Chem 315* and *Chem 513*). There is currently a nationwide discussion of the need to revise the undergraduate curriculum in analytical chemistry [1]. The Department of Chemistry at the University of Massachusetts Amherst has been actively involved in this debate [2, 3].

Table 1. Numbers of students taking *Chem 312* in Spring 1999 and 2000

	1999		2000	
Major	juniors	seniors	juniors	seniors
Biochemistry	12	8	22	11
Biology	3		1	2
Chemistry		1	1	1
Chemical Engineering		2		
Environmental Science	1	1	1	1
Food Science	1	2	2	5
Microbiology	1			
Natural Resources		1		
Totals	18	15	27	20

The students would be following the BA route rather than the more normal BS route.

Changes

I made several changes to the course as a result of STEMTEC and the ILI award. The most noticeable was to require a K-12 teaching experience. The most recent version of the course also featured research projects, in-class group work, a pyramid exam, more homework requiring the production of coherent prose, seven copies of the textbook [4] on short-term loan in the library, and the availability of some modern analytical chemistry equipment in the laboratory. The exact nature of these features were modified in 2000 in light of my experiences in 1999. Some of these changes had implications for the grading, details of which are discussed later.

The Teaching Requirement

The major impact of STEMTEC on the course, the inclusion of a K-12 teaching requirement, came initially as something of a surprise to the students. The students were given some leads—names, e-mail addresses, and phone numbers of teachers I had met through the STEMTEC workshops, and teachers who had participated in the previous year's activities, and details of the STEMTEC website—and told to make their own contacts. The task was not particularly onerous: students (in small groups) were required to participate in the teaching of a science topic to be decided in consultation with the teacher in question. After the initial contact was made, a total of two visits to the school was typically needed. The first was to meet the teacher and discuss the project in more detail, and the second was to deliver the lesson. To receive the credit for this part of the course, a 500-word report was required. To keep the students on task, regular progress questionnaires were handed out at approximately monthly intervals during the semester. This aspect of the course has been highly successful in getting students to consider (a) teaching as a career option, (b) the role of teaching as a strategy for learning, and (c) the responsibility of the professional scientist towards the next generation of scientists. All students were awarded the full 15% for this part of the course. In 2000, eighteen different classes were visited in twelve different schools. The classes were mostly elementary and high school classes with just one or two middle schools.

The following are extracts from the reports submitted by the students in the 2000 class. Almost all of these reports were positive in their attitude towards the experience.

> "This experience was definitely valuable to me as I am considering teaching biology or chemistry if I cannot get into graduate school for Forensic Science."
>
> "My experience of the STEMTEC program of this course allowed me to make choices and establish professional connections to last a lifetime. . . . I have recently been accepted into the STEP program."
>
> "I think I would be more inclined to teach after this experience."
>
> "I definitely need to consider teaching as a possible career."

> "As a result of this project, I have begun to look at teaching a little differently; I am now considering a career as a teacher, despite the relatively low salary."
>
> "I intend on becoming a science teacher and this experience helped to confirm my desire to teach."
>
> "I do not plan on becoming a teacher, but I think that professional scientists owe it to the community to occasionally go out into the K-12 sector and share their love for science."

Several students made comments along the following lines:

> "I am currently very seriously considering a career in teaching, although I would prefer to teach on the college level rather than the K-12 sector."

Several students reported that they were subjected to extensive questioning about "what it was like to be a college student."

As might be expected in a class of over forty students, there were some students who were not quite so enthusiastic:

> "This experience did not, however, open my eyes or encourage my interests in teaching. I have found that in the past, although I am smart enough to teach, I do not have enough patience to make a good teacher."
>
> "Now I know for sure that I do not want to teach for a living."
>
> "The value of the exercise for me was less than zero. . . I feel quite angry about being forced to complete such a thing as a requirement for a science course. . . I very much felt I was the victim of somebody's Ed.D. thesis. I think it would be much better for students to hear a thorough, well-informed lecture/presentation once a week, and perform homework, reading experimentation on their own in the meanwhile, than go to a weak chemistry class daily. Of course, my idea would be considered radical in an education system more concerned with controlling than educating students. This is unfortunate because high quality exposure to science in high school or even earlier is extremely important."
>
> "One suggestion that I have for the format of this component of the course is to do it earlier, say freshman or sophomore year. By the time people reach junior and senior year, I think they are pretty much set on what they want to become. Waiting until senior year is a little late to decide you want to become a teacher."

One or two students wanted the teaching to be optional (with extra credit available).

Of the 47 students who provided comments on the exercise, only two indicated that they considered the exercise to have little or no value. A further thirteen made comments to the effect that they would probably not have anything further to do with the K-12 sector. The remaining 32 students made comments to the effect that they would seriously consider some involvement in the K-12 sector, either as a teacher or as a professional scientist.

The Homework

There were twelve homework exercises: five of which required writing about chemistry topics mentioned in Zodiac (a novel by Neal Stevenson [5] and described by the publishers as an "eco-thriller"); five of which were solving numerical problems (one was exam number 2); one of which required providing one-word answers to questions relating directly to material in the textbook; and, one of which required writing suggestions for sample preparation and overall analytical methods. Efforts were made to get the students to work co-operatively on some of the exercises. Extracts from these different types of homework exercise are given below.

Type 1: Writing about chemistry

On page 85 of *Zodiac*, readers are informed that "plastic is essentially frozen gasoline." Starting with the chemical composition of some typical "plastics" (in particular the sort from which a van-load of stuffed penguins might have been fabricated) and the chemical composition of gasoline, critically examine this statement. Include other relevant chemical and physical properties of the materials in question. What tests could be applied to a sample of plastic to identify it? How would you measure (a) the concentration of iso-octane and (b) the concentration of lead in gasoline?

Some of the writing exercises were accompanied by the following instructions:

You are encouraged to work cooperatively on this exercise, and to share information about useful websites, textbooks, or other sources. This could reduce the amount of background research each of you has to do. Everyone must submit his or her own written piece, but you might consider implementing some peer review and editing.

Type 2: Solving numerical problems

A thin film of sunscreen on a quartz plate is placed in an absorption spectrophotometer and the absorbance measured at 300 nm. What percentage of the ultraviolet radiation at 300 nm is transmitted if the absorbance measured is 0.35?

This type of homework was often accompanied by the following instructions:

You may collaborate with other persons in the class and submit one set of solutions bearing more than one name. If you do participate in an exercise of this sort, then you need to prepare and sign a memo to me indicating that the submission represents a genuine collaborative effort involving each of the problems, and that you agree to accept a group grade for this homework. One memo with each of the group member's signatures will be sufficient.

Type 3: Providing one-word answers

The answers to the following questions can be found from reading Chapters 16, 17, and 18 in the course textbook.

Which of the following mixtures could not be separated by reverse phase HPLC?

(a) optical isomers of Naproxen
(b) the pesticides Carbaryl, and Methiocarb
(c) aflatoxins B_2 and G_2
(d) octanoic acid and 1-aminooctane
(e) fluoride, chloride, and bromide

Fill in the blanks with the most appropriate word (one word for each blank)

When trying to separate closely spaced bands, band _____ should be minimized. The rate of mass transfer between phases increases with temperature, thus increasing the column temperature might _____ the resolution. Octane, benzene and carbon tetrachloride are typical _____ compounds, whereas methanol, acetonitrile and ethanol are typical _____ compounds. Elution in HPLC with a single solvent composition is known as _____ elution. _____ elution in HPLC produces similar effects as _____ _____ in gas chromatography. The most common HPLC detector is the _____ detector, whereas for GC the detector which has almost universal response is the _____ _____ detector. Capillary electrophoresis can achieve plate numbers that are _____ times greater than those of chromatography. For the determination of chloride, the detection limit of _____ µg/L is best for _____ chromatography, but only _____ µg/L for an ion-selective electrode.

Type 4 Suggesting sample preparation and overall analytical methods

Many instrumental techniques require that the measurement be made on a solution Most samples for analysis are not solutions. Suggest procedures for preparing solutions of the analyte species for the following types of determination. (A) The determination of trace metals in a predominantly organic matrix (for example, the determination of cadmium, copper, and lead in cake mix); (B) the determination of a minor organic compound in a predominantly inorganic matrix (for example, the determination of PCBs in seagull eggshells); (C) the determination of inorganic components in an inorganic matrix (for example, the determination of iron, cobalt and nickel in dolomite); and, (D) the determination of organic compounds in a predominantly organic matrix (for example, the determination of amino acids in garlic).

Suggest overall analytical procedures (i.e., complete methods) for the following analyses. The determination of

(a) mercury in human hair
(b) sulfate, nitrate, chloride, phosphate in rain water
(c) caffeine in coffee beans
(d) dimethylarsinate in soil
(e) chromium in stainless steel.

STEMTEC Pedagogical Practices

With regard to the three pedagogical practices advocated by STEMTEC (students working in groups, inquiry, and alternative forms of assessment), there have been some changes. Students do work in groups in the laboratory class (for nine weeks out of the total of thirteen) and students were asked to work in groups on a number of in-class exercises. The laboratory group work has been a long-standing feature of this (and other analytical chemistry courses) where students perform experiments involving chemical instruments. With fifteen (or more) students in each lab section of *Chem 312*, there are not enough instruments to allow anything other than working in groups. For many years, the analytical chemistry faculty's approach has been along the lines of that pioneered by Walters [6,7,8] in which the students are assigned roles for the duration of the laboratory class. The most important of these is that of "group leader." The written instructions given to the students are reproduced below.

312 Laboratory Class: Group Experiments

The experiments to be done in weeks 5-9 and the project experiments (weeks 10-12) are to be performed in groups. Most of the groups will consist of three students, but there may be some groups of two and some of four. Groups will be assigned by the teaching staff. For each experiment, one of the group is assigned (by the instructor) to be the group leader. The other members of the group function as chemists working under the direction of the group leader. Each member of the group should have a different job (descriptions below) each week. For the experiments done in weeks 5-9, each group will produce only one report. It is the group leader's responsibility to co-ordinate the production and submission of the report. Each student in the group will get the same grade. The group task should be thought of as carrying out the requisite experimental work together with the production of a report. For the project experiments, each student will submit a separate report.

Each group member (including the leader) will write for each experiment a separate confidential report for the lab manager of not more than one page which will contain a description of what each person did in the lab, what each person did as a contribution to the report, how well the tasks were performed and how the group functioned (the good points as well as the bad). These reports should be handed directly to the laboratory manager and will be used as input in the award of points for "interpersonal skills." Each member of the group must read the information about the experiment before arriving at the laboratory and if there are any pre-laboratory exercises, these should be done individually. There will be a new group leader assigned for each experiment. Chemists should discuss their tasks with the group leader to ensure they cover all of the various tasks assigned to chemists during the five-week period.

The roles of the laboratory personnel are as follows:

Lab Manager (instructor)

Discusses experiment details with group leader initially, and later with other members of the group as necessary. Explains the operation of instruments and demonstrates their use. Functions as a consultant if problems arise that cannot be solved by the group.

Assistant Lab Manager (teaching assistant)

Discusses experimental work with group leader initially, and later with other members of the group as necessary. Explains the operation of instruments and demonstrates their use. Functions as a consultant if problems arise that cannot be solved by the group. Provides guidance in laboratory work. Ensures proper use of equipment and of laboratory techniques. Ensures adherence to safe working practices. Evaluates reports.

Group leader (student)

Researches the problem, discusses work plan with lab manager (or assistant lab manager) prior to start of experimental work. Discusses work plan with group members. Listens to comments, modifies plan. Co-ordinates work in lab, production of report and its submission.

Chemists (depending on group size there could be 1 - 3 chemists).

Chemists carry out tasks assigned by the group leader after discussion. These tasks could include:

Preparation of solutions for calibration of instrument
Preparation of samples for analysis
Measurements of all solutions (standards and samples)
Recording results in laboratory notebook
Sharing results with other group members
Copying results for other group members
Performing calculations (may include use of computer to plot calibration function)
Estimation of uncertainty in calculated values
Additional statistical evaluations or calculations
Writing parts of the report
Creating a visual record of the experiment

The structure for the laboratory group work was not significantly different as a result of my STEMTEC involvement, though the use of written individual reports was an innovation aimed at dealing with the problem of students who did not contribute fully to the group activity. A full 5% of the overall grade was awarded for interpersonal skills (see later); a low score in this category could easily affect the final letter awarded.

I reduced the number of in-class group activities in 2000 compared with the number in 1999, without any apparent ill effects. A poll of the students (written responses at the end of a class period) showed that about one-third of the class preferred lectures over in-class group work, one-third preferred in-class group work over lectures, and about one-third had no strong preference. Students were encouraged to work in groups for the homework exercises, and while they undoubtedly did this, they were reluctant to submit group solutions.

In addition to this resistance to the concept of homework groups, there was a certain amount of hostility towards the laboratory groups as well. Discussion with individuals revealed that the concern was mainly the feeling that there is a danger that their grade is compromised by the presence of weaker students. This probably arises from little or no exposure in previous classes to any kind of co-operative learning situation. In order to get students to work in groups, it is necessary to give credit for group work; however because credit is given, students are dissatisfied because of the perception of the influence of the weaker student(s) in the group. This situation is unlikely to change until students are introduced to co-operative learning early and often in their undergraduate careers.

The research project (worth 6% of the overall grade) was a genuine inquiry-based exercise. Several of the homework exercises required research prior to construction of the response. Almost all of the students regarded the World Wide Web as the first place to look for information. Very few students looked in the library.

None of the exams was multiple choice, so in that sense they were "alternative forms of assessment." Only about 40% of the overall score was awarded for the students' knowledge of analytical chemistry; the remaining 60% was awarded essentially for their abilities as students. Thus, compared to courses in which a higher percentage of the grade is awarded for knowledge of the content, it might be argued that this course represents the use of alternative methods of assessment. The pyramid exam was based on the concept of allowing students two attempts at an examination with a period in between, in which they could consult with each other. The two attempts were given relative weightings of 70:30. The exam selected for this mode was the third in a series of in-class exams and was given on two consecutive days (the UMass timetable occasionally produces a Monday schedule on a Thursday, thereby producing meetings on two consecutive days of a class which if offered on Mondays, Wednesdays, and Fridays). The exam contained numerical problems, true or false choices, fill-in-the-blanks, and essay responses. The second day's exam contained the following instructions:

> Read everything before doing anything and follow the instructions given at the end. The answers you hand in today will be worth 30% of the overall grade for this exercise. You do not have to rewrite solutions for which you wish the answer provided yesterday to be included. Indicate clearly which answers are being carried over (if any).

The "instructions given at the end", informed the students that they didn't have to answer all the questions ("Answer question 5, either question 1 or 3, and any other two questions").

Assessment of the Effectiveness of the Course

The overall grade (in 2000) was made up as follows, exams 35%, lab exercises 20%, homework 20%, teaching activity 15%, attendance 5%, and interpersonal skills 5%. There were four exams: three in-class "hour exams" and a final exam. One of the in-class exams was a pyramid of the form that the students took the exam twice (on consecutive days) with the points split 70:30 between the two exams. The exams were worth 5, 5, 10 (pyramid) and 15% (final) percent, respectively. The laboratory class consisted of experiments for which full instructions were provided and whose reports were awarded a total of 180 points, the laboratory notebook was assigned sixty points and the project 100 points. In 1999, the breakdown was a little different in that only 30% was awarded for the exams and the lab was worth 24%.

The percentage of the various grades awarded are given in Table 2.

Table 2 Percentages of grades

Year	A	AB	B	BC	C	CD	D	Totals
1998	39 (14)	28 (10)	17 (6)	11 (4)	0 (0)	3 (1)	3 (1)	100 (36)
1999	48 (16)	33 (11)	9 (3)	3 (1)	6 (2)	0 (0)	0 (0)	100 (33)
2000	39 (17)	32 (14)	23 (10)	0 (0)	2 (1)	4 (2)	0 (0)	100 (44)

Note: Numbers in parentheses are numbers of each grade awarded. For 1998 and 1999, an A meant 80+, in 2000 an A meant 85+. Each half letter grade corresponds to a 5 point band.

The mean overall percentages and standard deviations are given in Table 3 for the years 1998, 1999, and 2000, together with same information for the percentages on just the exams.

Table 3 Overall scores and exam scores

	Overall			Exams		
	1998	1999	2000	1998	1999	2000
mean	74.7	80.0	81.7	59.1	66.6	69.6
std dev	7.8	7.3	6.7	12.6	8.8	10.4
95% CI	2.6	2.6	2.0	4.3	3.1	3.2

Note: In 1998 and 2000 exams were worth 35% of total, in 1999 exams were worth 30% of total. Total numbers are given in the last column of Table 2.

These data may have some interesting properties. Assuming that there is no difference in the students' abilities over the three years and that the data are normally distributed, it may be deduced that the performance of the students has improved over the three years. There is a significant difference (at the 95% confidence level) between the overall percentages (and the exam percentages) for 1998 and 1999, and for 1998 and 2000. Had I not increased the threshold for the awarding of letter grades by 5% for 2000, there would have been 31 A's awarded.

It is always difficult to assign causes to effects that are observed in the teaching of classes of relatively small numbers of students over relatively short periods with what might be considered relatively minor changes in the pedagogy adopted. In comparison with the methods used in 1988, there has probably not been a significant change in the relative weighting given to the students' abilities as analytical chemists and the students' abilities as students, although the activities involved in the computation of the overall grade were considerably different. Thus, the improvement in overall performance in the course, as evidenced by the improved overall scores, is interpreted as due to the changes implemented. This improvement was evident for the two years following the changes made as the result of STEMTEC. One possible factor accounting for the improvements seen in 1999 and 2000 over the 1998 performances is the award of 15% of the grade for participation in the K-12 teaching exercise. However, the structure of the grading was such that this 15% for participation in the class replaced a similar percentage for similar activities in the 1998 grading scheme, and thus the real improvement observed may be attributed largely to the improved performance in the various examinations i.e., in the students' abilities as analytical chemists. ■

Acknowledgments

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Bio

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INTEGRATION OF MULTIMEDIA INTERACTIVE WEB TOOLS WITH IN-CLASS ACTIVE LEARNING

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In this paper, we present our experience with an introduction to engineering course in which we used a combination of active and collaborative teaching methods, multimedia web-based material, and web-based interactive tools. The students were engaged in active learning in class with methods such as demonstrations, hands-on work, and group work. After class, the students used the web-based material that we developed, such as multiple choice quizzes, interactive applets, and animations. We have also developed a number of web-based course management tools that were used by the course instructors. We conclude that both the students and instructors had a very positive experience from using this combination of methods.

Introduction

In this paper, we introduce the methods we have used in an introduction to engineering freshmen course entitled, *Introduction to Computer Networks*. The course was designed with the following goals in mind: 1) to provide preliminary knowledge on the structure of the Internet (software and hardware); 2) to get the students used to collaborative team work; and, 3) to improve the students' writing skills.

In the traditional classroom, the material is presented by the instructor while students are passive listeners. This presentation style can be suitable for some students but lacking for others [5,6]. Today's students, also referred to as Generation "digital," have a very limited attention span. They are used to a number of multimedia stimulations, such as voice, video, as well as interactivity, while surfing the net. From the instructors' point of view, traditional teaching methods, especially in large classes, lead to very complex course management issues such as material distribution, homework grading, and grade posting.

To enhance the students' educational experience and simplify the instructors' course management tasks, we have used the following four components in *Introduction to Computer Networks*:

1. *Web-based instructional tools* — For the students, we developed the following modules: on-line quiz, grade check, and keyword search. And for the instructor: create/edit quiz data base, create/edit grade roster, and analyze quiz performance. This suite of tools is installed on a server computer (e.g., Windows NT) and in order to access the tools, the clients (students and instructors) need to have a web browser. The software tools have the following characteristics:
    a. Easy to use
    b. Easy access (anytime, anywhere)
    c. Platform independence (i.e., can be accessed from MAC, PC, Unix computers)
    d. No software installation is required on the students' or instructors' computers
2. *Active and collaborative learning* [1-6] — bookend, pyramid quizzes, demonstrations, hands-on experiments, group summaries, and muddiest point
3. *Multimedia course material* — multimedia class notes, animations, and applets
4. *Static web based material* — announcements, class notes, homework solutions

Figure 1 shows how these components were used by the students in class and after class.

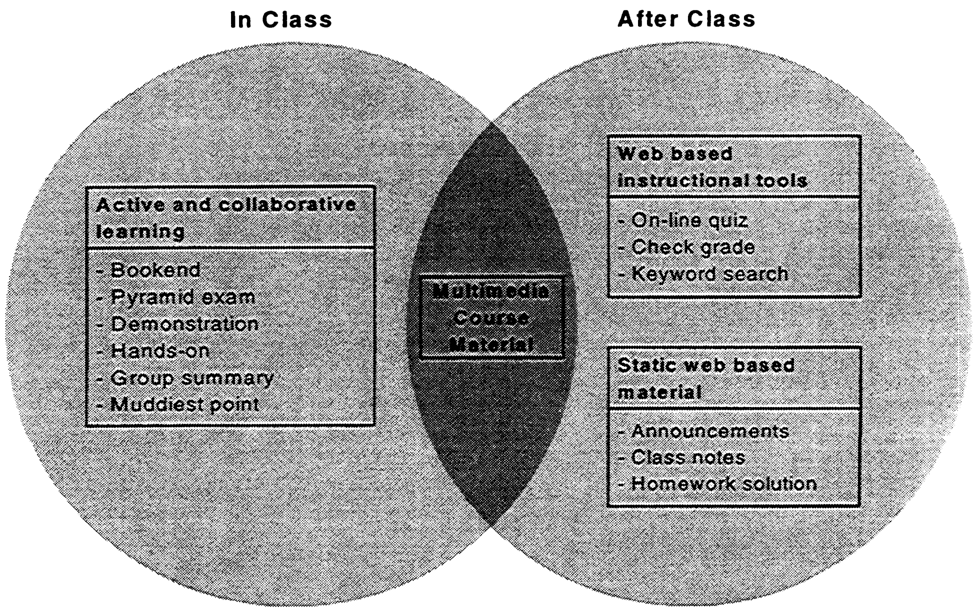

Figure 1: Integration of components used by the students in class and after class

Active and Collaborative Learning

The purpose of collaborative learning is to enhance students' ability to communicate with their teammates, develop critical thinking and problem solving skills, create positive attitudes, and increase the students' motivation to learn and understand more [2-6]. Examples of collaborative learning methods that we used are pyramid quizzes [1] and group projects.

Active teaching and learning techniques bring the course material to life, making it more interesting. These techniques also enable bi-directional communication between the instructor and students, and among students themselves. We have used the following techniques: bookend, muddiest point, demonstration, and hands-on experience.

By combining active and collaborative teaching and learning methods, the classroom becomes lively, energetic, and fun. Students not only learn more and perform better in the material, but they also learn to work in teams and improve their social interaction skills. We ask the students to voluntarily form groups of three. If they cannot find a group, we assist them.

Each lecture (75 minutes) follows a bookend structure as shown in Figure 2.

Pyramid Exam	Muddiest Point	Lecture	Demo & Hands-On	Summary
10 min.	2-7 min.	30-45 min.	10-15 min.	10 min.

Figure 2: The bookend structure [7]

The bookend lecture includes the following units:

1. **Pyramid quiz** (10 minutes) [1]: every week, there is a multiple-choice quiz with thirty questions that covers the material discussed in class during the previous week. The first round of the pyramid quiz is performed by each student individually, then these students turn in their quiz. In the second round, the same quiz is taken by groups of students, after which each group submits the quiz with their names and signatures of each group member.
2. **Muddiest points** (2-7 minutes): after the lecture is over, each group gets together and submits to the instructor, via e-mail, a number of questions regarding topics

covered in the lecture. In case there was no time left at the end of the lecture, the groups e-mail us the questions after class. Selected questions are answered in class during the following lecture and before the new material is presented.

3. **Lecture:** instructor introduces new concepts in front of the class.
4. **Demonstration and/or hands on experience:** instructor demonstrates in class the new concepts that we have introduced during the lecture and let them experiment in the computer lab. Examples of demonstrations in class are networking hardware equipment.
5. **Summary:** each group summarizes the lecture concepts in about 200-300 words per lecture. This summary is e-mailed to the instructor.

We also assign a group project—each group is assigned to work on a more accurate and elaborate summary of a particular lecture. The group project that is posted on the web includes text, figures, and links to additional material on the topics covered in the specific lecture. We provide the students assistance with web page design.

Web-Based Material

Our web based educational material is composed of:

1. Static web-based material
2. Multimedia web-based material that includes applets, pictures, sound and video
3. Interactive web-based tools that include quiz, check grade, search terms, and interactive applets

In the static web-based material, we include the class announcements, the course syllabus, class notes and also links to other activities, such as multimedia and interactive material. A screen shot of the class website is shown in Figure 3.

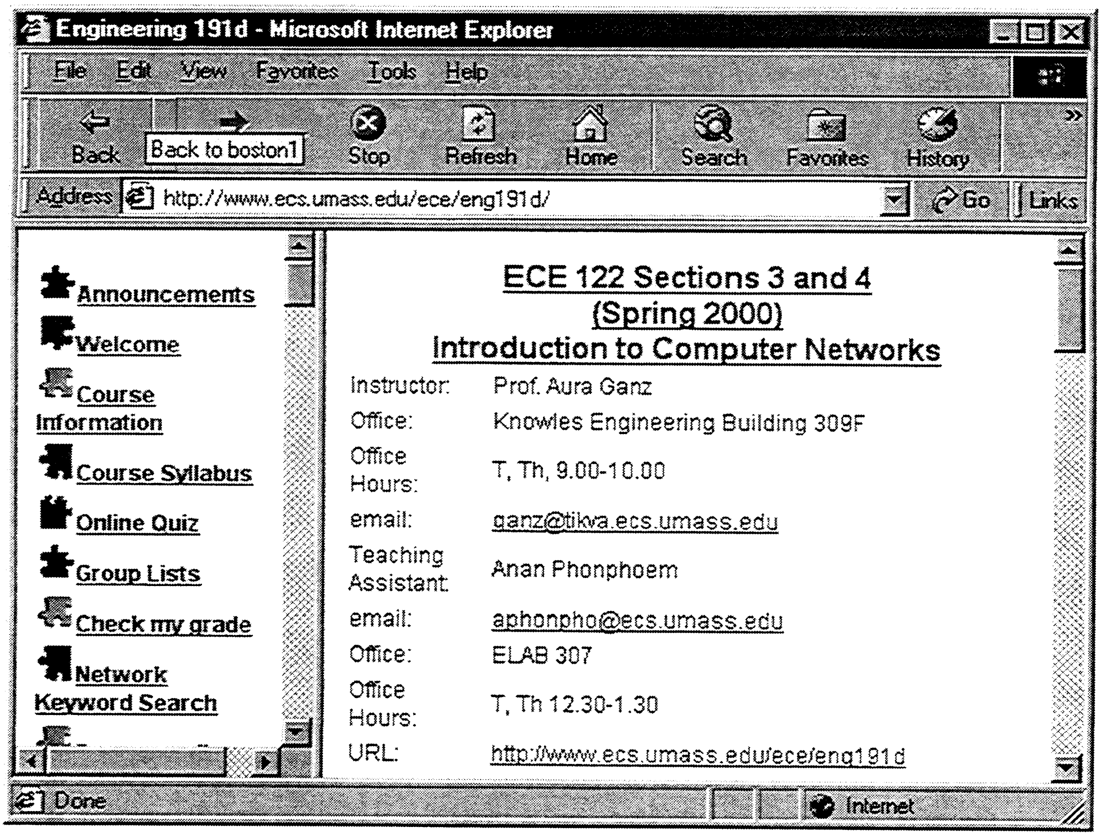

Figure 3: Freshmen engineering class website

The multimedia course material includes applets, pictures, sound, and video. Figure 4 shows an example of an animation applet integrated with the video of the instructor and Figure 5 depicts the use of photography and drawing.

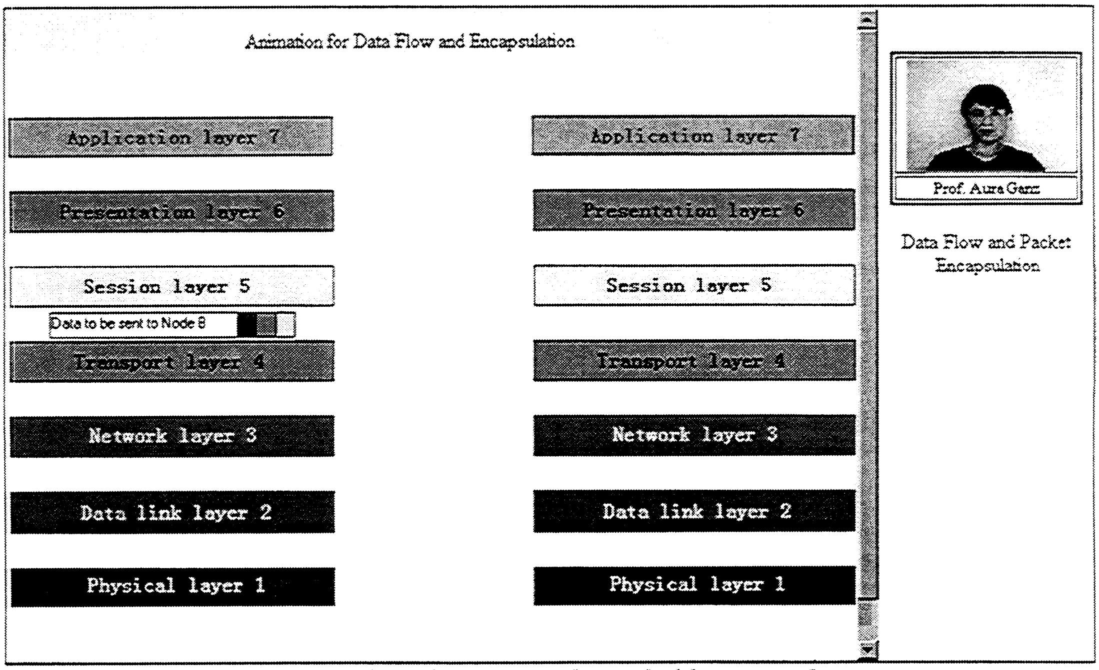

Figure 4: Animation applet and video example

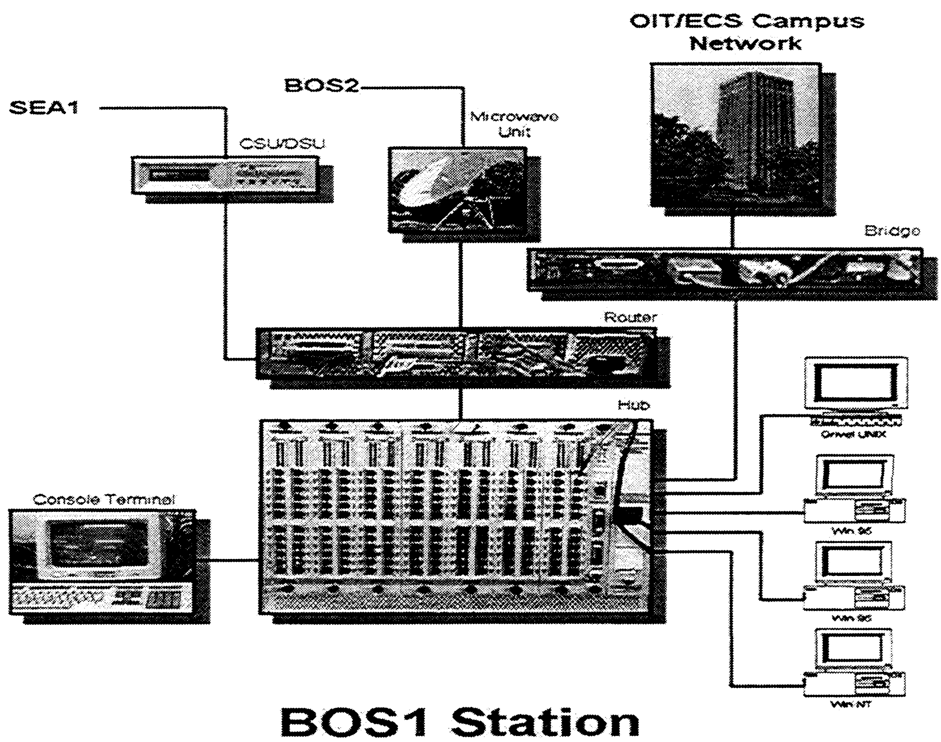

Figure 5: The networking laboratory equipment: combined picture and drawing

The students use the quiz software in order to practice for the pyramid quiz that is taken in class. The quiz software will generate a quiz on the fly from a specific topic chosen by the student. As shown in Figure 6, the software generates a multiple-choice quiz sequentially or randomly. After the student submits the multiple-choice answers, the software will grade the submission and generate another page to provide feedback to the students about their answer (Figure 7). If the choice is wrong for the question, the correct answer is displayed. In order for students to remember the question easily, the questions are also shown with the answers. The feedback also includes the score of the current quiz, the time spent on the quiz, and accumulated average score of all the quizzes the student has taken. The software has no record of students' identity, and students can leave the quiz session at any time. However, the software will keep a record of answers for further analysis.

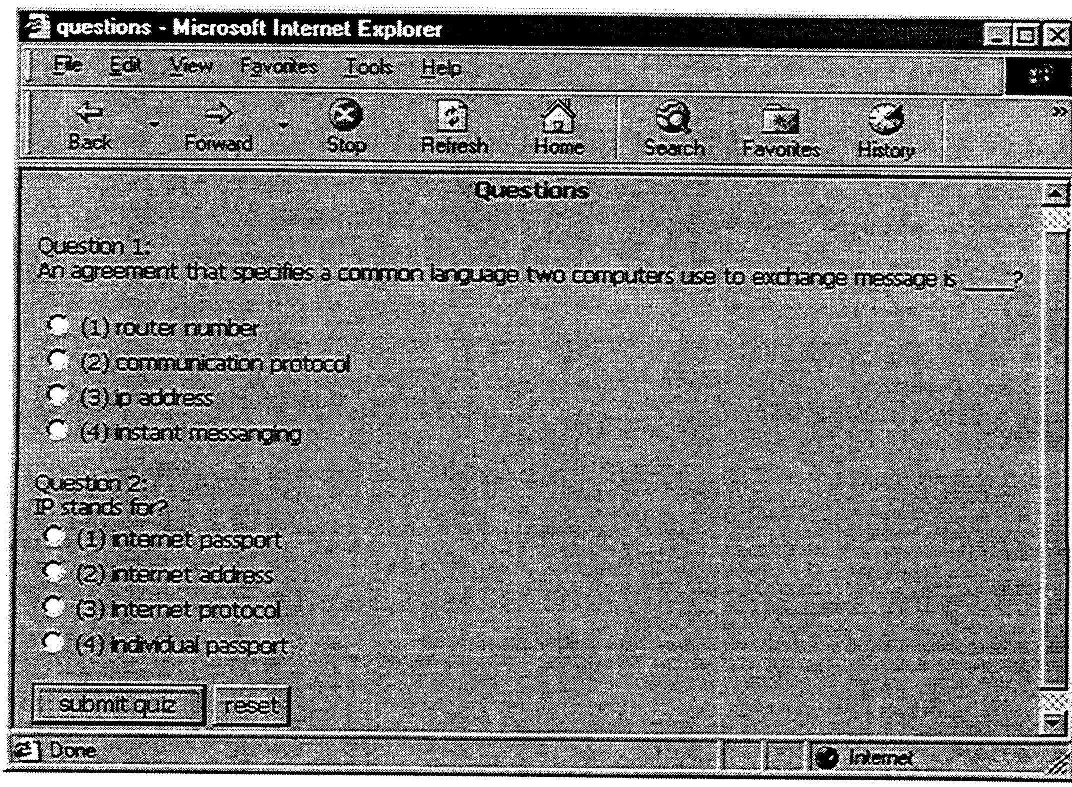

Figure 6: Multiple-choice questions screen

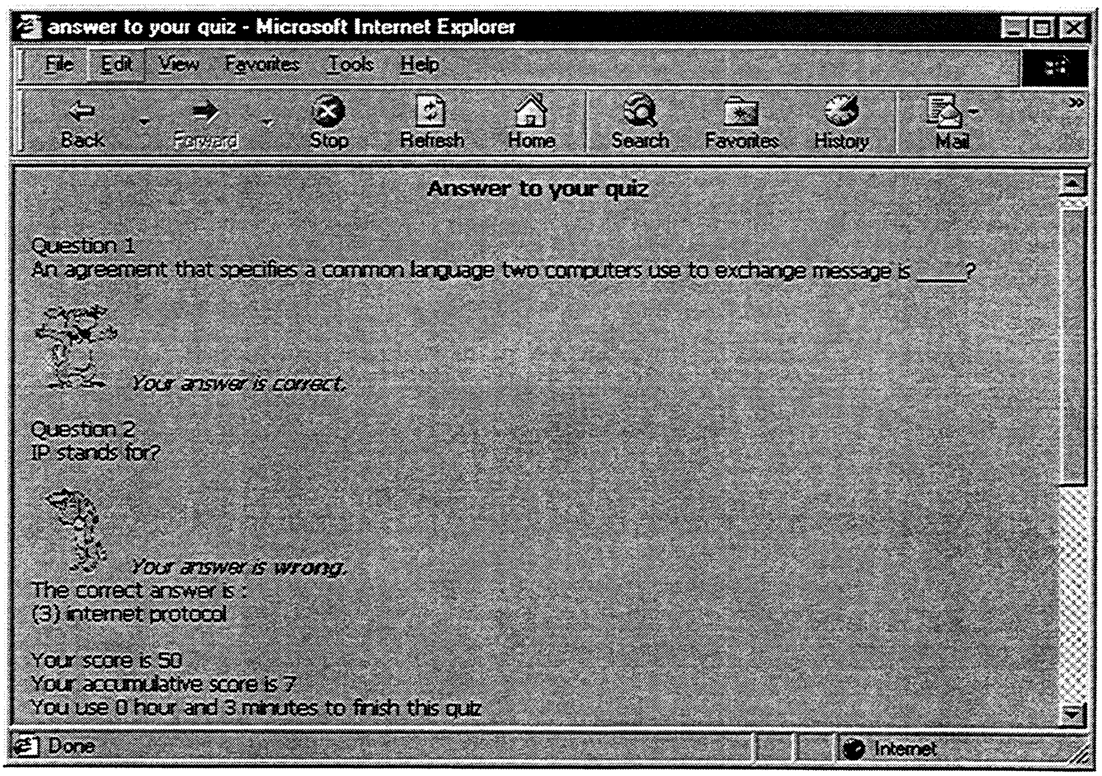

Figure 7: Quiz feedback screen

Most of the students are very interested in their grades (for each homework, quiz, test) and how these grades compare with the class average. However, in order to continuously and frequently provide this information to each student, instructors spend a considerable amount of time. The check grade on-line tool can help solve these problems. Students can find their grades and the class average immediately after the instructors update this information. To protect the privacy of this information, each student accesses this information using his/her password. After a student logs in to the system using their password (e.g., student ID), the software will display the grades and class averages as shown in Figure 8. In this case, we see the student's grades and class average for the lecture summaries (lect2 – lect9) and for the individual (Ind.Quiz) and group part (GrpQuiz) of the pyramid quizzes. Since each assignment in class has a different weight, the students can also learn these weights by clicking the "Show me weight" button.

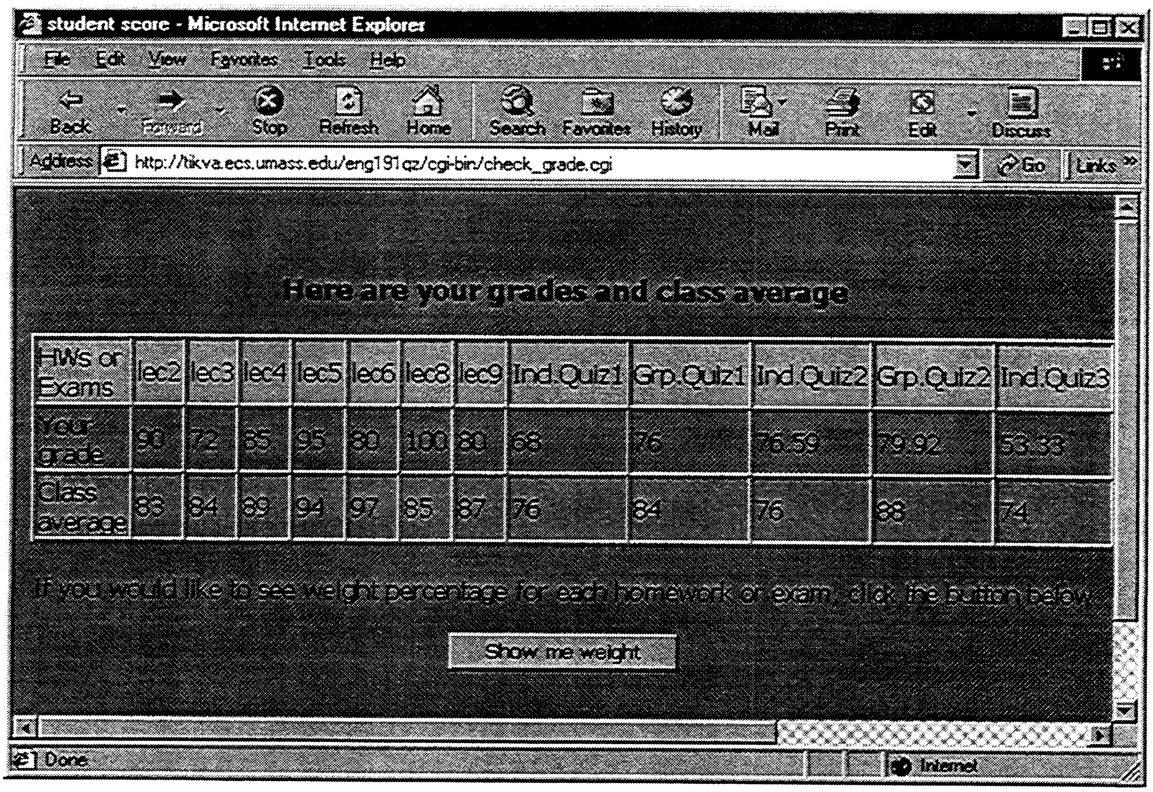

Figure 8: Check grades on-line screen

We have also implemented a search term tool that provides the students with the option of checking definitions of networking terms. A screen shot is provided in Figure 9.

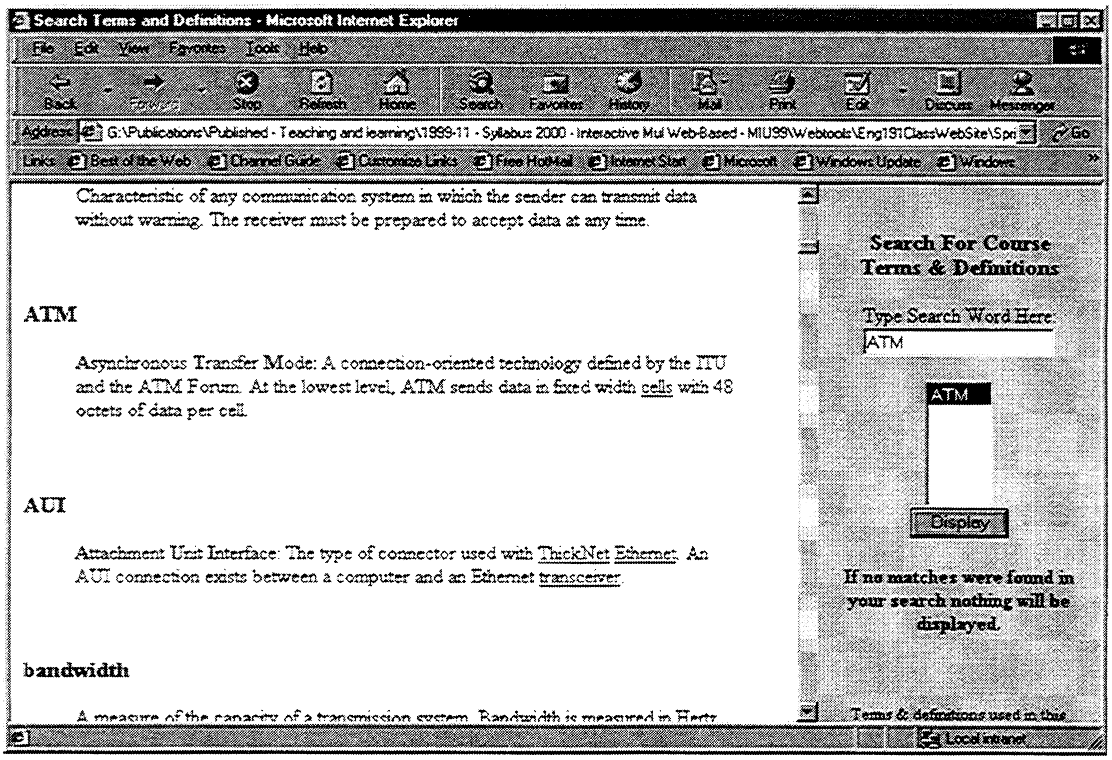

Figure 9: Search terms screen shot

We are currently developing a number of java applets that will be used in future computer networks courses, e.g., the shortest path applet presented in Figure 10. The applet technology gives students the opportunity to interact with the software by changing a number of system parameters and viewing their impact on the network behavior. For example, in the shortest path routing applet the students can define the network topology, link weights, the source and destination, etc. The students can view both the graphical and text output of the shortest path algorithm, improving the students' understanding of this algorithm.

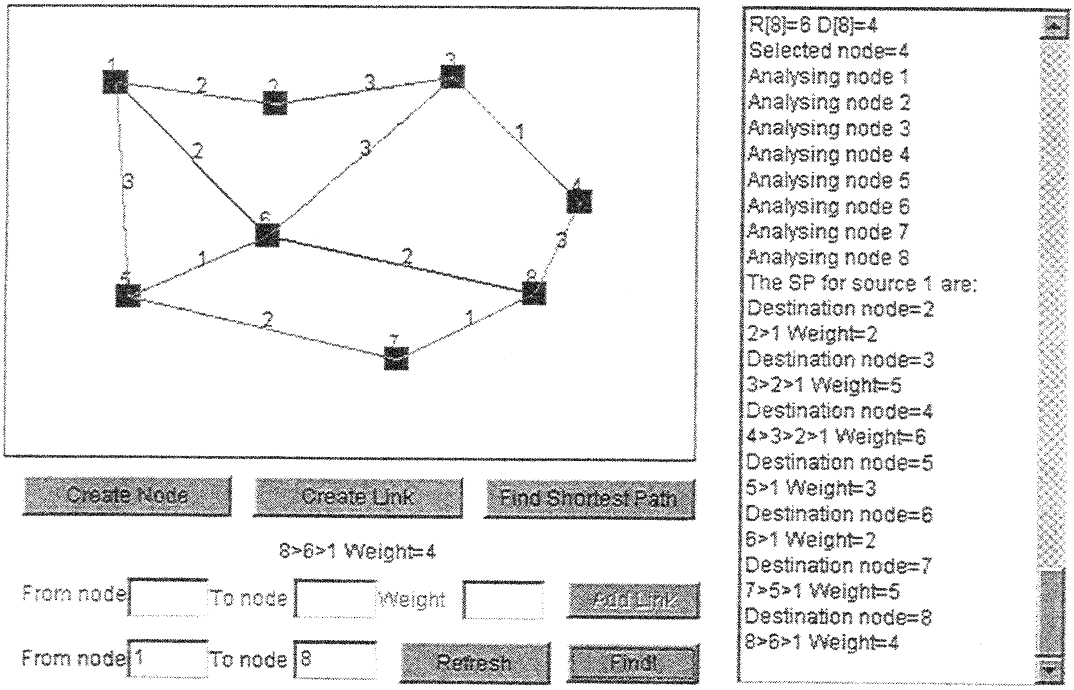

Figure 10: Shortest path applet screen shot

On-Line Class Management Tools

There is a large amount of information that needs to be managed by the instructor, i.e., the quiz file, the grades file, student information, etc. The administration software is password protected and can be accessed only by the course instructors. Access to the administration software is through a browser, leading to platform independence for the instructor.

There are four sub-functions in the administration module: view file, edit file, create file, and analyze results. For example, if the view file option for viewing the grades is chosen, the screen shown in Figure 11 will be displayed.

If the edit file option is chosen, the instructor can edit many different files (e.g., students' records, quiz file, grade file, etc) using a java-based interface as shown in Figure 12. The editing is done locally and only when the instructor saves the file are the file contents updated on the server.

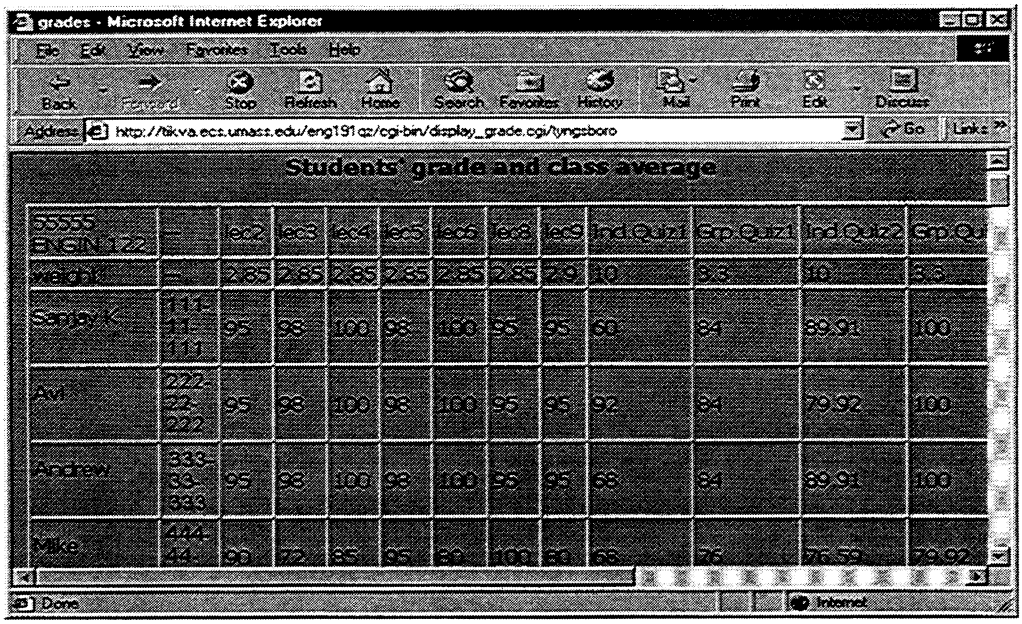

Figure 11: Students' grade screen

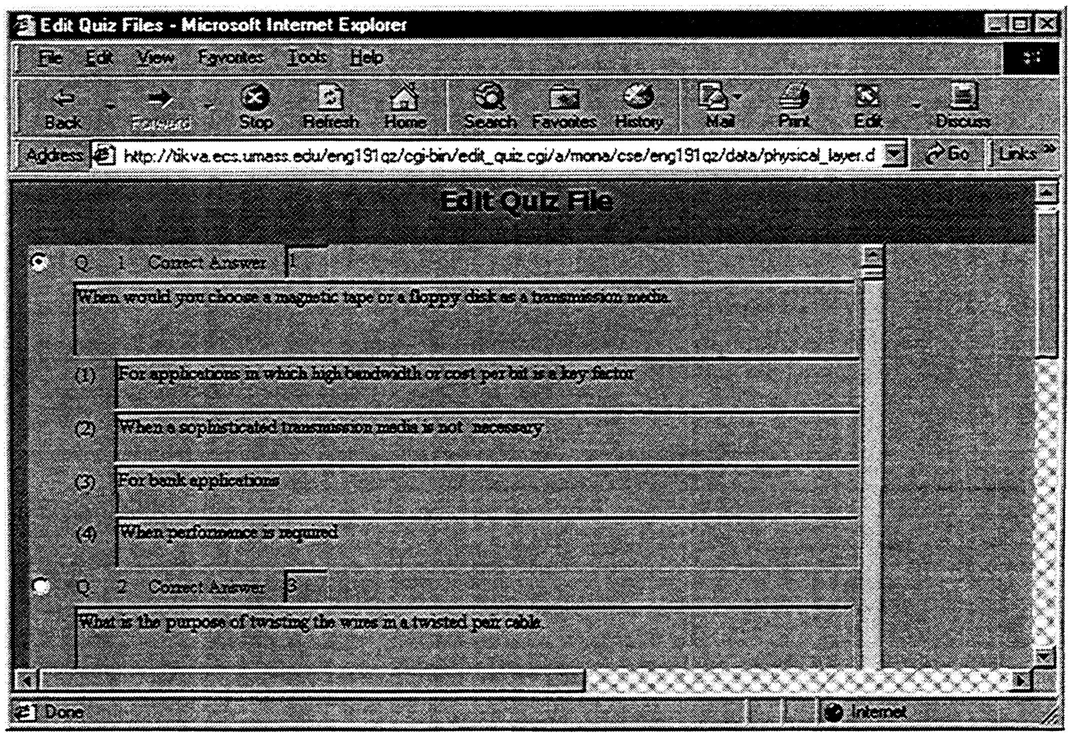

Figure 12: Java-based interface for editing the quiz file

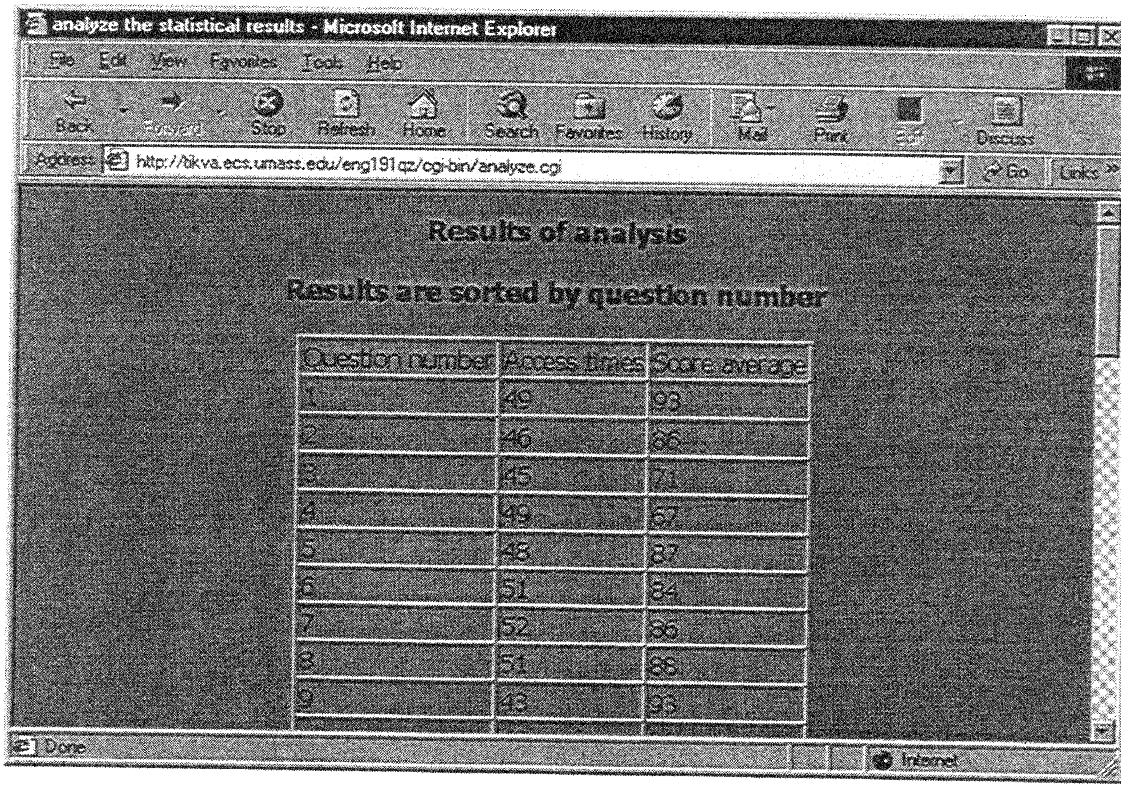

Figure 13: Results analysis screen (sorted by question number)

When students take the quiz, the software that grades the quiz saves statistical information that includes time, question number, and answer. Each quiz file has one statistical file associated with it. This file can be used by the instructor to analyze the students' performance. Clicking "analyze results" button on the administration page enables analysis of the statistics collected so far. There are three methods to analyze the statistical files. First is to display results according to the question number, second is to display results according to percentage of correct answers, and third is to display only partial results (such as choosing only easy questions or difficult questions).

Figure 13 shows statistical results sorted by question number for a specific chapter. The table shows how many times each question is accessed, and the average score for that question. If you are more interested in the difficulty of the questions, you can use the second analysis method that sorts the questions by percentage of correct answers. An instructor can use this information for clarifying the concept in class or just reformulate the question or answers.

We found from these statistics that each question in the data base was accessed numerous times, i.e., the students use the quiz tool very often in order to practice for the pyramid quiz taken during class time. We do not have any statistics regarding the identity of the students that took the quiz. As explained before, the students prefer to stay anonymous so that they can practice the quiz as many times as needed without being monitored by the instructor.

Feedback

We evaluated the students' satisfaction with some of the components we have used. Table 1 provides the results we collected from all 55 students who took the class.

	Students' feedback (% of total students)	
	Satisfied	Dissatisfied
Muddiest points	71	29
Pyramid quizzes	92	8
Hands-on demonstrations	98	2
Quiz website	83	17
Course website	100	0

Table 1: Student feedback on a number of components we used in class

We observed the following:

- For muddiest point, 29% of students were not satisfied because the muddiest point assignment is counted toward the students' grade
- For quiz website, 17% of students were not satisfied because the on-line quiz material contains some typos and wrong answers; this result leads us to consider adding a feedback or bug report page included in the class website, and it would be a good process for polishing the material
- Students seemed to be more interested in the hands-on demonstrations on network hardware/software components
- Homework/project grading was easy and fast
- Students preferred to form a group by themselves rather than be assigned by the instructors. Voluntary groups have shown better results in the projects.

Summary and Future Work

In summary, our experience teaching this course was very positive. We have enjoyed observing the students participate and show interest in class as well as in the after class activities. Based on the students' feedback presented above, we conclude that this was a successful experience for the students. Obviously from the instructors' perspective, it provided considerable savings (time, photocopying, paper).

Our next steps in this project are to: 1) enhance interactivity through animations of abstract concepts and multimedia (video and voice) contents; 2) interact with STEMTEC project to better understand the learning processes and course assessment methodology; and, 3) obtain constant feedback from students and instructors. ■

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Bio

Professor Aura Ganz is the Director of the Multimedia Networks Laboratory at the University of Massachusetts Amherst (UMass). Her research interests include multimedia networks, web-based instructional technologies, wireless networks, security, and high speed networks. With her graduate students, she has developed web-based instructional technology software that was implemented in a number of undergraduate and graduate courses at UMass. She has received the Best Paper award in Foundations in Education Conference 1999. Prof. Ganz received her Ph.D. in Computer Science from Technion, Haifa, Israel. She has published over 120 papers in various journals and conferences. Prof. Ganz is also the co-founder of a UMass spin-off, EnrichNet, Inc., that provides software solutions for multimedia support in wireless and wired LANs.

Prof. Anan Phonphoem received his Ph.D. in Electrical and Computer Engineering at the University of Massachusetts Amherst in May, 2000. His research interests are computer networks, wired-wireless LANs and protocols. He received his B.Eng in Electrical Engineering from Prince Songkla University, Thailand in 1990. Between 1990 and 1991, he worked for Advanced Micro Devices (Thailand) as a reliability test engineer. From 1991 to 1994, he worked for Nawaloha Industry Co., Ltd., Thailand, as an engineer. In 1994, he received a scholarship from the Royal Thai Government, Thailand, to pursue his M.S. and Ph.D. studies in the U.S. In 1996, he received an M.S. in Computer Engineering from the University of Southern California.

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THE THAYER METHOD: STUDENT ACTIVE LEARNING WITH POSITIVE RESULTS

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Graduation from West Point requires successful completion of four courses in the mathematical sciences. These core mathematics courses include topics in discrete dynamical systems, differential and integral calculus (single variable and multivariable), differential equations, linear algebra, probability, and statistics.

The instructional system employed throughout the core is the "Thayer Method," named for Colonel Sylvanus Thayer, "the Father of the Military Academy." In the Thayer Method, traces of cooperative education and "discovery learning" are evident. It is quintessential active learning. The West Point catalyst is the fundamental principle that cadets are responsible for their own education.

Introduction

Efforts to "reform" mathematics education have flourished since the mid 1980's. Release of the National Council of Teachers of Mathematics Curriculum and Evaluation Standards in 1989 [1] and initiation of the "Calculus Reform" crusade were two catalysts in the campaign. Curriculum and pedagogy were subjects of the major reform efforts.

It is difficult to correctly and concisely summarize the current state of mathematics education reform. Efforts to provide such a summary in the popular press often cite the "New Math" reforms of the '60s. Nowadays, it is even fashionable to employ belligerent terms to report on the controversies; for example, the term "Math Wars" was applied to describe a controversy over curriculum reform efforts in California [2].

However, it is possible to provide a few themes common to many of the contemporary reform movements in mathematics education. Cooperative education, inquiry based learning, and student active learning are three such themes. Moreover, the role of modern technology in the teaching and learning of mathematics is usually prominent in every discussion.

Part of the problem and indeed, the source of some controversy, is the difficulty in assessing and evaluating curriculum or pedagogical change. It is not possible to produce evidence

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as from an experiment in chemistry or physics. Instead, one considers a combination of anecdotal, qualitative, and quantitative information. It is necessary to draw "conclusions" with caution and to phrase statements with care and precision. The approach is that of a social scientist, not a physical scientist.

In this paper, I provide a brief description of a mathematical sciences program that has many features of today's "reform" programs. The themes cited above are present. In particular, student active learning is evident, as it has been for more than a century.

We begin with some historical remarks. See references to support and supplement this necessarily brief account [3,4,5,6,12].

Historical Remarks

The United States Military Academy (USMA) at West Point will soon begin the third century of its existence. By act of Congress on March 16, 1802, the country's first national education institution was established. America's first Commander in Chief, George Washington, had anticipated the need for officers educated in the science and art of the military, especially artillery and engineering. With its Washington and Jefferson pedigree, West Point swiftly emerged as a source of officers and engineers for the young nation. The westward expansion required design and construction of roads, bridges, and the development of a national infrastructure. As the first engineering school in the country, West Point was a wellspring for faculty needed to staff engineering programs emerging in public and private institutions of higher education.

The core of the West Point educational process and program was (and still is) mathematics, the physical sciences, and engineering. First and foremost are the mathematical sciences, the foundation and cornerstone of a West Point education since Sylvanus Thayer's term as superintendent.

Sylvanus Thayer was Superintendent of the Academy from 1817 to 1833. He was born in Braintree, Massachusetts on 9 June 1785. Thayer graduated first in his class from Dartmouth in 1807. His best friend at Dartmouth was George Ticknor who later became one of the great educators of Harvard College. Ticknor and Thayer were friends for life. President James Madison appointed Thayer to study at West Point on the recommendation of General Benjamin Harrison.

Thayer completed the West Point curriculum in one year and accepted a commission in the Corps of Engineers. He was assigned duty as Inspector of Fortifications for New England. In 1810, Thayer was appointed Assistant Professor of Mathematics at West Point. During the War of 1812, he became convinced of the need to modify the method of preparing army officers for duty.

In 1815, Thayer was sent to France to study the French system of preparing engineers and to purchase books, maps, and equipment. He visited École Polytechnique and the artillery school at Metz. Thayer was influenced by the "prescription system," a dominant feature of the military education at École Polytechnique. "Prescription" was also in place at the University of France established by Napoleon. Science was the core of the subject matter—all courses were set down (hence the term "prescription")—and attendance was mandatory!

While Thayer was in France, George Ticknor was visiting Göttingen. The liberalism, academic freedom, and the electives in the curriculum, which Ticknor observed at Göttingen, were the basis for reforms that he later promoted at Harvard College. The adoption of these Germanic based reforms spread throughout American higher education.

In 1817, Thayer was appointed Superintendent of the Academy. His work as superintendent earned him the honorary distinction, "Father of the United States Military Academy." We limit our remarks to his contribution in establishing what are often called the Thayer System and the Thayer Method. For my purpose, the former refers to the merit based system of evaluation that Thayer instituted, and the latter applies to the mode of learning and instruction.

Thayer's merit-based system evaluated each cadet's performance in academics, military preparation, and discipline. Every cadet was graded on every activity. A competitive atmosphere was created, but the Corps of Cadets appreciated the elimination of favoritism. Instruction was in small sections grouped by ability. There was monthly resectioning based on order of merit. The smaller class sizes necessitated more instructors and these were drawn from the ranks of the military, in fact from a pool of graduates of "the old West Point."

The beginnings of the Thayer System are described well by the eminent historian, Stephen E. Ambrose in *Duty, Honor, Country*. Ambrose's book was reissued in 1999 as a paperback (with an afterward by General Andrew J. Goodpaster, Superintendent from 1977-1982) [3].

The Thayer Method

In order to graduate from West Point, a cadet must successfully complete four courses in the mathematical sciences. These core mathematics courses include topics in discrete dynamical systems, differential and integral calculus (single variable and multivariable), differential equations, linear algebra, probability, and statistics. Maximum capacity of each section is eighteen cadets.

The Thayer Method of instruction is employed in the core mathematics courses. To be sure, the present day version is a modification of the version used in the early part of the 19^{th} century, but some essentials remain. For example, question and answer interaction and student oral presentations to the class are a major portion of every class period.

To present a sense of the mid 20^{th} century West Point classroom in mathematics, we refer to two articles by COL Charles P. Nicholas, Professor of Mathematics, USMA [7,8]. COL Nicholas graduated from West Point in 1925. He was Head of the Department of Mathematics from 1959-1967. His perspective of the Thayer Method as practiced in the West Point Mathematics classroom is that of a student learner and a professorial practitioner.

In *Preparing the Weapon of Decision* [7], COL Nicholas begins by writing, "A fundamental purpose of mathematics at West Point is to prepare the cadet's mind for a career of military decisions." Following a discussion on the technical objectives of mathematics at West Point (the subject content of the core mathematics courses and the role of each in the curriculum and the military careers of West Pointers) Nicholas writes:

> But to return to the most fundamental purpose of all, it is the function of mathematics at West Point to shape the cadet's mind into an effective instrument of military leadership. This is accomplished by a particular method of teaching which, although features of it are certainly used in other good colleges, is perhaps nowhere else directed so uniquely toward the objective of leadership as at West Point. This method of teaching regards mathematics as an intellectual discipline, and not as a tool for computation; it regards a mathematical process as a pattern of

> thinking, and not as a manipulation of symbols. In short, the course is taught as a liberal arts course in the true sense of that term, and not as a cookbook course of formulas for the technician. The emphasis is on the understanding of fundamental concepts, on precision of analysis, and on logic.

He then provides an account of General Ulysses S. Grant's "mental pattern" in formulating a battle plan for the attack at Vicksburg. His point is that Grant was "supremely confident of [his] ability to figure out an original solution of an unexpected problem" and that he was "accustomed to reasoning in terms of the abstract". Grant (and other great military leaders) had acquired the ability to understand their own thoughts with clarity and to formulate them effectively to others. It is COL Nicholas' contention that proper training in mathematics provides the means to acquire these abilities and, therefore, the study of mathematics is essential in development of successful military leaders.

Specifically, the mental traits that are characteristic of the greatest military leaders are [7]:

- The habit of thinking fundamentally, or the ability to see each new problem as representing a more general design to which basic principles are applicable; the power of abstraction

- The habit of confidence that one's own mind contains all the resources needed to solve a problem; the capacity to learn for one's self

- The habit of logic

- The power to communicate fluently and precisely

A fundamental principle at West Point is that cadets are responsible for their own learning. Indeed, certain assignments have the force of a direct military order.

The following summary of specific features of the Thayer Method is described courtesy of my colleague, LTC Donald Engen, Assistant Professor in the Department of Mathematical

Sciences and USMA '81, in his unpublished manuscript entitled, *Thayer Method of Instruction*. There is some overlap with what appears above.

Components of the Thayer Method implemented in the core mathematics courses at West Point are summarized as follows:

- For each class, a text lesson is assigned. This assignment includes a reading and specific problems associated with the reading material. Each cadet is expected to "work the problems." (Note: Prior to 2000 these problems were called "drill problems"; the current terminology is "suggested problems.")

- "One learns mathematics by doing mathematics." Cadets are encouraged to be active learners and to "do" mathematics. Group work is encouraged and expected. Special projects are a major portion of each core mathematics course—work on these projects is done in teams of two or three.

- Cadets are required to study the concepts of each lesson in such a way as to be ready to use them in three ways:

    1. To express them fluently in words and symbols
    2. To use them in proof and analysis
    3. To apply them to the solution of original problems

- The instructor's goal during each lesson is to cause the maximum number of cadets to actively participate in the day's lesson. One of the instructor's roles is to facilitate the learning activity in the classroom. This may take the form of a question or a remark to clarify a point.

- Class begins with the instructor's questions on the assigned text lesson. Cadets are asked if there are questions on the assignment. Example problems are worked and discussed. Cadets are sent to the boards to work in groups of two or three on specific problems that are provided (so called "board problems"). These board problems may be similar to the problems assigned with the text lesson or they may be "original."

- Cadets are selected to recite on the problems they work. Questions are encouraged.
- The instructor spends a few minutes to discuss the next lesson. This practice is commonly called the "pre-teach."

We return to Stephen E. Ambrose for another brief summary of the Thayer Method:

> ... each cadet received an assignment from the text each day, upon which he recited and was graded the next. The teaching was intensely practical, with little or no attempt to impart the theory of a subject. Many found the method deadly, while others prospered under it; for Thayer, the important point was that it seemed the most thorough system for imparting knowledge [6].

During the academic year 1998-99, I taught at West Point while on sabbatical leave from University of Massachusetts (UMass) Amherst. The course was *MA391: Introduction to Mathematical Modelling*. There were thirteen students in the course: six seniors ("firsties"), six juniors ("cows") and one sophomore ("yearling"). All students had completed the "core." My plan for the course was to import several topics usually covered in the undergraduate mathematical modelling course (*MA456*) at UMass. Moreover, I intended the course to be "project based" as *MA456* has been since my colleague, George Avrunin, designed it in the mid 1980's. We provide a brief description of the modelling course below [9].

The course is an introduction to the mathematical modelling process. Different types of models in use in the physical, social, behavioral, biological, life sciences, and engineering are analyzed. For example, we attempt to introduce examples of deterministic, simulation, probabilistic, statistical, and axiomatic models. Special consideration is provided to models in the social sciences since many of the students have experience with models in the physical sciences and engineering (e.g., models of spring mass systems, electrical circuits, planetary motion). Moreover, in recent years there has been an explosion of applications of the mathematical modelling process in the social and life sciences. For example: in medicine, we can consider the problem of modelling the immunology of AIDS and in public policy we have the problem of modelling stratified populations to "fix" Social Security and Medicare.

Some of the topics we have covered are: population models (including several different models of one population as well as models of competing populations from ecology); models of social choice (how groups make decisions); economic models (the Cobb-Douglas production model); models of the epidemiology and the immunology of AIDS; models of strategic armaments of two countries (Richardson's Arms Race Model); and, simulation models in planning and development. For more on some of these subjects see one of the texts formerly used in *MA 456* at UMass Amherst [10].

In our treatment, we stress that mathematical modelling is an ongoing and dynamical process that is useful in daily life. An early activity is to use the daily newspaper as a source of "scenarios" for mathematical modelling problems. Later, we introduce "modeller's minute," a few minutes of class time for members (or the instructor) to present a modelling scenario recently encountered (e.g., how does a university decide how many students to accept in order to have a first year class of 4,321?).

I include a brief description of the four projects. Note the progression from describing and analyzing an existing model from the literature to designing a model to solve a problem of their own choosing.

Project 1. This is a report on a model that the students must find in a book (other than the text) or a scholarly journal. They are provided a series of questions that they are expected to address in the **context of their written project report**. (Emphasis added—we expect the answers to be woven into the text and not listed as a litany.) For example, what is being modeled—what is the nonmathematical problem under investigation—what are the underlying nonmathematical assumptions of the model—are these assumptions reasonable or not—what is the mathematical representation—is this representation accurate—what additional assumptions are implicit in the precise formulation of the model—are these assumptions reasonable—what mathematical reasoning is applied—what are the results—what type of interpretation is made of the mathematical results—is this interpretation tested in any way—is the interpretation sound. The length of the paper is left to them, but we expect five to ten pages with references.

Project 2. The students are given a choice. Present two distinct models of the same phenomenon (as was shown in our prior study of several different population models) or present one model applied to two distinct phenomena (as the logistic equation is used to model population or to describe learning theory in psychology). They are expected to address the same series of questions as in Project 1.

Project 3. This is an activity on simulation. They may report on a simulation from the literature or they may develop a simulation on their own. They are advised to look ahead to the final project when they will be asked to create a model on their own. It is allowed to have Project 3 serve as a beginning of the final project. Again, a series of questions are provided and they are expected to answer these questions in the context of the project.

Project 4. They are expected to develop a model on a topic of their own choosing. Several examples are provided as suggestions (many are topics treated by former students).

At West Point, I intended to cover some of the topics previously covered in modelling courses at USMA but not at UMass (not surprisingly, some of these were military applications). Students would do projects in teams of two or three (members would be changed from project to project). Oral reports on the projects would be presented during class. West Point's fully residential setting is conducive to group work. At UMass Amherst, I can (and do) encourage my students to work in groups. However, students with a long commute to campus or demanding work schedules can do collaborative work only with extraordinary effort (and sometimes not at all).

As it happened, the course I offered at West Point in Fall 1998 resembled the UMass course more than its West Point counterpart. (Course End Reports are written for each course at West Point. I had access to these for the mathematical modelling course.) For example, students were allowed to select the topics for the projects. The cadets seemed to welcome the opportunity to choose. This choice was in contrast to the required projects in core mathematics courses where the entire course is assigned the same prescribed problem (perhaps with different data for each section).

On the day projects were due, student teams presented oral reports or "briefs" to the class. Immediately, I noticed the effect of the Thayer Method. The presentations were well organized, and delivered with confidence and clarity. There were questions from the audience and answers and discussion followed. The experience of two years of practice briefing in the core courses was evident.

In my modelling course at UMass Amherst, I also require that students report to the class on their projects. My objectives are twofold: to provide an opportunity for the students to learn about the wide variety of mathematical models (this they acquire by listening to their classmates and participating in the discussions) and to provide experience in "communicating mathematics." The second objective has the potential to develop personal skills useful in their future endeavors. Many former students have told me that they had very little experience in presenting reports prior to taking my modelling course (which I had suspected from my many years of listening).

During the spring term of 1999, I made changes in the course. I attempted to include a few more components of the Thayer Method. Course handouts were distributed in "daily" packets and combined with reading and problem assignments from the text(s). This would align with the assignment of a text lesson for each class. For example, when we investigated the axiomatic modelling of social choice and Arrow's Impossibility Theorem, supplemental packets were distributed daily with a specific reading assignment and problems. The reading and problems were discussed at the beginning of the next class. However, I avoided student board work on "drill" problems except in a few special cases.

Let me digress somewhat and comment on Arrow's Impossibility Theorem. The Arrow is Nobel Laureate Kenneth J. Arrow. Professor Arrow was a co-winner of the Nobel Prize in Economics in 1972, in part for his work on the Impossibility Theorem. The setting seems to be more in the realm of political science than economics as it is the problem of considering what criteria determine a fair method for a group to make a choice. There's not too much controversy if there are a finite number of voters and two candidates. Majority rule might do the job just fine.

But what if there are three or more candidates? Now it gets a bit more complicated—in fact it gets a lot more complicated. Suppose we can require that each voter make an ordered choice of preferences—so each voter submits a ballot with a #1 choice, a #2 choice etc. How to choose a winner? Majority rule? There may be no majority choice. Plurality? Well, there may be a tie. Even with a clearly defined tiebreaker there are problems with a plurality system. There is a method called, "plurality with run-off." There are point systems (one such is called the Borda count). There are elimination methods. There are "head to head" systems (one is called the Condorcet method). However, it is possible to construct an example with five candidates and 55 voters, such that each candidate is a winner under exactly one of the five systems cited (each voter rank orders the candidates on a ballot with a first choice, a second choice, etc.). There is a video, *For All Practical Purposes*, produced by COMAP with an elementary exposition of this example; also, chapter eleven in *For All Practical Purposes* offers further insight [11].

Professor Arrow considered the problem of deciding which criteria characterize a "fair voting system." Or, as we say in mathematics, what set of axioms must be satisfied by such a fair voting system? In the language of mathematical modeling, we are asking for an axiomatic model of a fair voting system. More generally, we are asking for a clear process to pass from the level of individual choice to the level of societal choice.

Before proceeding with Arrow and his axioms, let me comment that this topic produces more lively debates and class discussion than any other I have covered in my modelling courses. We have developed a series of examples of various voting methods. Some are factual (e.g., primaries and general elections, political parties' selection procedures [at conventions], Baseball Hall of Fame elections, and a mathematics department's method of selecting its personnel committee). Other examples are manufactured to illustrate the complexity of the process of determining "society's choice." Obviously, the United States presidential election of 2000-2001 will be featured in our next course! [10,11].

One axiom that is easy to state, and not at all controversial, is the Axiom of Unanimity—namely, if all voters choose candidate A then society's choice is A. Another possible axiom would be the transitivity of society's choice—namely, if society prefers candidate A over candidate B and society prefers candidate B over candidate C then society prefers candidate A over candidate C. Transitivity is not as innocuous as it seems!

Oh yes, clearly we don't want to allow a dictator in a society that seeks a fair election process, so we "axiomatize away" the existence of a dictator. Arrow's Impossibility Theorem states that no "fair voting system" is possible where a "fair voting system" is one that satisfies five axioms (one of which is Unanimity, another is the Nonexistence of a Dictator). For a complete statement of all five axioms *and* a complete proof, read Michael Olinick's *An Introduction to Mathematical Models in the Social and Life Sciences* [10]. Yes, even in these days of mathematics courses without proofs, we cover in class the proof of a theorem of Nobel stature, and we do so honestly and completely.

The impact of Arrow's work on economics, political science, and philosophy is an important historical event. It is a substantial example of mathematics applied to the behavioral sciences. Moreover, it provides an example of axiomatic mathematical modelling.

For the project briefings, cadets are expected to use whatever visual aides or technology is needed. I was quite favorably impressed with what I experienced during the briefings. Midway through the fall semester, I stated my objective to "master *PowerPoint*" before the term was through. The unit on Arrow's Impossibility Theorem would be my "briefing." And so it was—with great pride, and a little fear, I clicked through definitions, axioms, examples, and the proof. Well, truth be known, the proof is a little too long for someone of my very limited typing skill. I did use the boards and a few transparencies. When I finished my debut, one of the cadets offered the observation, "Sir, it's possible to do the *PowerPoint* in color." "Yes, I know," I responded politely, "That's my objective for next term."

The *PowerPoint* presentation of Arrow's Theorem that I had prepared for Fall 1998 was, indeed, upgraded to a "bells and whistles" version for Spring 1999 (full color with sound and animation). When the "file" was complete I sent an electronic version to the cadets in the fall course. Some of them responded with brief notes.

The slide with the axiom, "***There is no dictator!*** " now contained a clip art character ("the dictator"). Our "dictator" periodically appeared on the *PowerPoint* slides in anticipation of the "punch line " of the proof. The *PowerPoint* presentation worked superbly on the desktop in my office. It also worked like a charm in the department's seminar room. Unfortunately, the computer cabinet was locked when I went to test it in my classroom. When I made the presentation to the class we discovered there was no sound card in the classroom's computer and the projection unit was stuck in an out of focus position! My full color with sound and animation *PowerPoint* briefing fizzled. We were able to salvage the essentials of the exposition (with proof) of Arrow's Impossibility Theorem. I know that I demonstrated some teaching principles that day—perhaps not exactly as planned, but we did no harm. Teaching with technology is not learned by talking about it—as with learning mathematics, it is learned by doing.

One of the student project briefs deserves mentioning. One team based their project on a required assignment from the core course, *MA206: Probability and Statistics*. The briefing included a *tour de force* in *Mathcad*, the computer algebra package used in all core mathematics courses. The class appreciated the presentation and asked several incisive questions. Many class members had wrestled with the problems that the briefing team handled with relative ease—especially with the *Mathcad*. I allowed the discussion to run well past the allotted time and on to the end of the class period. My main contributions were the decisions to allow the discussion to continue for most of the class period and to stay out of the way! This was quintessential student active learning and teaching!

In my opinion, there were a few reasons why this particular presentation was so well received by the audience. The subject matter was a problem that most of the class had worked on with some diligence, but not complete success. They were familiar with the material and had tried to take ownership, but they didn't yet "own it." However, some of their peers had been able to develop a solution to the problem and communicate the solution in a manner that they understood.

Later that semester, I formulated a modelling problem that came to me from the baseball coaches of the Atlantic 10 Conference. Some of the coaches were unhappy with the schedule. Apparently, the same schedule had been used for several years. This seemed easy enough to remedy and, probably, no mathematical modelling was necessary! More importantly, however, was an inequity in the schedule. Some teams were scheduled for away series on the last two weekends of the season. Now "home field" advantage is a part of baseball—but presenting some teams the "home field" advantage for two consecutive series at the end of the league schedule is an inequity.

There are two divisions in the A-10 Conference, North and South. Each division has six teams. Conference games are played on weekends. Each team plays a three-game series with another conference team (in a weekend series, one team hosts all three games at its home field). Each team plays one three-game series with every team in its division and each team plays a series with two teams from the other division. As stated above, the three game series is played over a weekend at the home field of one of the two teams.

After solving the scheduling problem on my own (in the context of an axiomatic model), I posed a simplified version to the class. For example, I first stated the problem as if there were only one six-team division. Each team would play a series with each of the other five teams. We imposed one axiom that required no team have more than three home series. As another axiom, we required that no team would have less than two home series. We required that no team would host consecutive series for the final two weekends. Finally, we required that no team would have consecutive away series during the final two weekends. The first question is an existence question for this system of four axioms. Does such a system exist? If so, produce a "model" i.e., a schedule with the desired properties. Or, perhaps, there is a contradiction in the axiom system—in which case no such schedule can be constructed. Finally, there may be the possibility that one of the axioms can be established from the others. The last point is probably not of interest to coaches. Nor is the question of uniqueness of a schedule if one such should exist!

As the class made progress on the first version, we formulated the general problem—namely, the full conference schedule with interdivision play. We factored in the need to rotate the schedule from year to year. We discussed an attempt to accommodate a "weather condition." This condition would schedule the "cold weather" teams for an away series at sites of "warm weather teams" early in the season. As it happens, this weather condition cannot be imposed uniformly without, say, adding "warm weather" teams to the conference. In fact, this year a warm weather team, Virginia Tech, left the Atlantic 10 to become a full member of the Big East Conference.

I announced that a solution was good for a 100-point bonus. Several complete solutions were submitted and awarded the appropriate bonus points. I sensed that there was a genuine interest in the problem. They enjoyed working it. I conjecture that the number of submissions would not have declined "much" if there were no bonus points. One solution paper was exceptionally clear and well organized. With the student authors' permission, I submitted their schedule model to the Atlantic 10 Conference. It is my understanding that the Atlantic 10 Baseball Schedule to be used in future years is the one designed by the students and the professor. By the way, the solution can accommodate teams leaving and entering the conference, as with Virginia Tech's departure.

Conclusion

It is quite legitimate to question the effectiveness of some of the staples of contemporary educational reform. For example, what evidence do we have to justify the implementation of, say, a cooperative education approach to teaching middle school mathematics? Is the evidence "hard" or "soft"? What methods should be used to assess and evaluate? In this spirit, we ask whether the Thayer Method is effective.

With little more evidence other than my own experience of three years of teaching at USMA, I have a positive and definite affirmative answer. Yes, it has been very effective at West Point. My answer is framed in the context of the special mission of West Point and the highly structured and compact curriculum. The mission of West Point is as it was two hundred years ago—to prepare officers educated in the science and art of the military. The current mission statement of USMA, "Educating Army Leaders for the 21st Century," reads in part, "To educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country; professional growth throughout a career as an officer in the United States Army; and a lifetime of selfless service to the nation."

I know of no other academic institution that monitors its curriculum as carefully and conscientiously as is done at West Point. The academic curriculum is integrated and interactive. The academic units communicate in a real and substantial way. Interdisciplinary activity is genuine, not contrived, superficial, or perfunctory.

Recently, the Academy considered a change in technology. My officemate was a point person on the proposed change and the recipient of numerous phone calls, e-mails and visits from faculty in other departments. The faculty worked as good custodians of the curriculum in their departments and programs—they asked the questions that needed to be answered. It was impressive to observe.

Would this "system" be successful at another institution, say, a liberal arts college? Maybe. Yes, if the faculty and students had a common sense of purpose and commitment. There are such institutions. Ditto for universities. But recall the words of Ambrose quoted earlier when he wrote of the Thayer Method, " Many found the method deadly, while others prospered under it..."

Finally, I've been asked to comment on how the benefits to the military leadership component are equally applicable to corporate or government leadership roles. I see this as two questions. One asks if the West Point model can be used in an institution other than West Point. My brief answer is "Yes, if that institution is properly structured and receptive." To be honest, I am not the one to answer that question—there are many at West Point who can, and probably have in their papers, books, and lectures. The second version of the question is whether those who go through West Point can "make it in the civilian world." Well, novice as I am about West Point history, I can start a list that includes presidents, corporate executives, founders of large and successful companies, highly successful basketball coaches, educators, engineers, and even, the celebrated Abner Doubleday. But the real important question is about the current state of the institution. In the last three years, I've had students as good or better than I've known anywhere. I'm not quite ready to sign on to Andrew Jackson's description of West Point as "the best school in the world."[12] But, I am certain that Charles Dickens got it right when he said of the Academy, "The course of education is severe, but well devised..." ■

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This paper is dedicated to the United States Corps of Cadets and to the memory of COL Sylvanus Thayer.

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ALTERNATIVE MODES FOR TEACHING MATHEMATICAL PROBLEM SOLVING: AN OVERVIEW

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Various modes are proffered as alternatives for teaching mathematical problem solving. Each mode is described briefly, along with general purposes, advantages and disadvantages. Combinations of modes are suggested; general issues identified; recommendations offered; and feedback from teachers summarized.

Introduction

The National Council of Teachers of Mathematics (NCTM) has asserted that "problem solving is an integral part of all mathematics learning" and has recommended increased emphasis on problem solving. While NCTM's principles and standards acknowledge that "there is no one 'right way' to teach," its vision does not specify alternatives to traditional instruction other than that students may learn "alone or in groups." [1]

Mathematics teacher educators can help prospective and in-service teachers by providing them with a repertoire of teaching modes in order to improve students' mathematical problem-solving abilities. A "mode" is a way of structuring students' learning environment for teaching purposes. This term is used here to distinguish modes of teaching from "methods" or "strategies" for problem solving, *per se*.

This article outlines a variety of modes for teaching mathematical problem solving, listed in increasing order of student group size and roughly from student-centered to teacher-centered:

EXPLORATION	PAIRED	COACHING
INDIVIDUAL	THINK ALOUD	BRAINSTORMING
PROBLEM POSING	INTERVIEW	FAMILY
INCUBATION	GAMING	LARGE GROUP
COMPUTER	SMALL GROUPS	PRESENTATION

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Purposes of Modes

Common to all these modes are a dozen general purposes, seen from the teacher's perspective and linked to NCTM's principles and problem-solving process standards [1]. Each purpose references NCTM Principle(s) and/or NCTM Process Standard(s) outlined in the key below:

NCTM Principles	NCTM Process Standards
E Equity	PS Problem Solving
C Curriculum	RP Reasoning and Proof
T Teaching	CM Communication
L Learning	CN Connections
A Assessment	RN Representation
K Technology	

(1) Practical Purpose: To conduct mathematical problem solving in a suitable setting within constraints of time, space, and resources. *Note: Modes are intended primarily for use in the classroom unless indicated otherwise.* PS

(2) Technological Purpose: To use appropriate technology for enhancing teaching and learning. K

(3) Pedagogical Purpose: To engage students in active problem solving and relevant learning. T

(4) Problem-Solving Purpose: To motivate students to apply their problem-solving skills and mathematical knowledge to solve a particular problem. *Note: All modes assume that the problem can be solved by most students within the time frame set by the teacher.* PS

(5) Cognitive Purposes: To stimulate students to think about the problem, and to help them understand related problem-solving concepts and methods. RP

(6) Affective Purposes: To build positive attitudes toward problem solving; to reduce math anxiety; and, to nurture the joy of problem solving. L

(7) Interactive Purpose: To encourage students to communicate about problem solving. CM

(8) Learning Purpose: To develop students' problem-solving skills and related mathematical knowledge. C,L

(9) Metacognitive Purpose: To develop students' ability to monitor, control, and reflect on their problem-solving processes. PS

(10) Cultural Purposes: To respect students' individual differences, heritage, values, and beliefs about mathematics; to include social, economic, and historical perspectives; to uphold college, state, and national standards; and, to promote equity in math education. E

(11) Assessment Purpose: To record students' problem-solving efforts in order to assess their progress. *Note: All modes require individual student reports.* A,RN

(12) Real-World Purposes: To develop students' appreciation for life skills involved in problem solving, and to acknowledge relevant application areas and career opportunities. CN

More specific special purposes are given for each mode in [2].

Modes

In order to help teachers choose a particular mode, each mode is described below in a synopsis, along with salient advantages vs. disadvantages (using the same numbering as the purposes above), along with selected references for follow-up reading. Full descriptions of all modes, including recommended grade/level, time frame, special purposes, and detailed operational guidelines for students and teachers are given in [2].

Exploration Mode

Synopsis: Each student selects a mathematical problem or puzzle to explore, discovers as much as possible about it, and prepares a "map" of what s/he finds. (This map is a guide to the features of the problem.) Students share their maps with each other and then with the teacher, who confirms what is actually needed to solve the problem/puzzle.

Note: This is also known as "Investigation" or "Discovery" mode and may be structured with specific activities for students to follow in stages.

Advantages and Disadvantages:

(1) Students may work in their own chosen space -- library, computer lab, or home. Yet, it's easy to lose focus and to lose track of time. (2) Students can use browsers and search engines via Internet, a

virtually unlimited resource for background information. Yet, they may become distracted by extracurricular information. (3) This mode is good as a warm-up homework assignment; good for introducing a new topic informally; and good for hands-on activity. Yet, without teacher control, students can fool around and might need content scaffolding. (4) It allows field work using real data and is an open-ended opportunity to investigate, experiment, and play—without having to solve the problem. Yet, some students flounder due to lack of structure; some drown in too many possible causes and effects. (5) Students can start thinking naturally and build their own cognitive structures. Yet, it's hard to overcome preconceptions, misconceptions, and mental blocks alone. (6) It's comfortable; there is no overt pressure on students; nobody is watching or demanding results. Yet, some students become frustrated when they can't make progress and may give up too easily. (7) Students can have internal debates about what to do next. Yet, their inner voices may be undeveloped. (8) Natural curiosity is nourished by discovery of potentially endless challenges. Yet, more questions than answers may arise; and there is no guarantee that students will learn underlying mathematics. (9) Students can build a sense of ownership for the problem and use metacognitive skills to guide their own exploration. Yet, these skills may be undeveloped. (10) Students can share cultural aspects of the problem in a "map" for others to use. Yet, they may just represent their own perspective. (11) Students can take pride in self accomplishment. Yet, the teacher can't assess them very well without direct observation. (12) Life skills include: investigation, experimentation, heuristic reasoning, and independent decision-making. Yet, life isn't just a bowl of exploration!

Reference: See [3] for models of investigation for teaching college science.

Individual Mode

Synopsis: Each student works alone on a problem and annotates his/her own work. The teacher then provides a list of the problem-solving skills and mathematical knowledge involved in solving the problem for the student to identify which s/he actually used and which of them need improvement.

Advantages and Disadvantages:

(1) This mode presumes a quiet and convenient place to work. Yet there is limited private space in the classroom, and intrusions are inevitable at students' homes. (2) It is suitable for use of calculators or personal computers. Yet some students can't afford them. (3) Individual mode is commonly used for homework, drill, and testing. Yet, it is an overused mode with no "teachable

moments" for the teacher. (4) The student has control, can work at his/her own pace, and can focus on the problem. Yet, without help, it is often hard to start, hard to get unstuck, and easy to give up. (5) Mental discipline is exercised, and writing annotations may increase clarity and understanding. Yet: students may just rush to get an answer; writing can interfere with their thinking; there is only one source of ideas, no check against wrong thinking, and no teacher to undo misconceptions. (6) Some students are more comfortable problem solving individually and can build confidence. Yet, lone failures can damage self-esteem. (7) Students can tap their inner voices, and annotations provide a good basis for self communication. Yet, there is no real interaction, no verbalization, and no one to urge them on; so many students prefer collaboration. (8) Students can find out privately what they don't know or can't do. Yet, they can become discouraged if there is too much to be learned. (9) By annotating their own work, students must reflect on it; students can develop a sense of ownership for the problem -- especially if they are successful. Yet it is human nature not to reflect on failure. (10) Students tend to work in their own established sub-cultural context. So, there is little incentive to consider a larger cultural perspective. (11) Students' annotations help the teacher diagnose skills and knowledge they need. Yet, students may believe that it's not their job to assess their own work. (12) Life skills include: test-taking, independent thinking, organization, time/energy management, self-discipline, responsibility, and perseverance. Yet, many people would rather not work alone in the real world.

References: See [4] for a classic book on individual problem solving, and see [5] for a more recent analysis of heuristics, control, and beliefs.

Problem Posing Mode

Synopsis: After problem solving (in another mode), each student is invited to propose new problems and to share them spontaneously with other students. Manipulative materials may be provided.

Note: A "new" problem here means new to the student, not necessarily an original problem.

Note: Problem Posing includes "problem presentation", which concerns how to present a problem—its context, wording, and illustrations—after the essence of it has been *posed*.

Advantages and Disadvantages:

(1) Manipulative materials may be suitable for this mode (depending on choice of problem). Yet, it is a chore to store and retrieve them. (2) An intelligent tutoring system might help students through stages of problem posing. But, such "inspiration" software is not available in schools yet. (3) This is an unusual student-centered activity: the teacher is free to observe or participate; it's particularly good for reinforcing problem-solving skills and knowledge—perhaps on a Friday in review for an impending test; and, it's a good opportunity for creative students to shine. Yet, most students are not used to it and have difficulty getting started; it's hard to detect if students are on task. (4) Students may produce some interesting problems. Yet, many student-posed problems are not very mathematical or not relevant or too silly or too hard or just canned imitations. (5) Posing problems involves both creative and systematic thinking; it can spark insight and solidify understanding. Yet, some students shut down mentally because it seems too challenging. (6) There is no immediate pressure to solve problems, which allows students' confidence in their mathematical creativity to grow. Yet, some students worry that their posed problem isn't good enough. (7) Communication skills are involved in writing and editing problem statements, as well as in explaining a problem to another student. Yet, some students are reluctant to share their posed problems. (8) This mode can motivate students to review related problem-solving skills and knowledge. Yet, even motivated students may find it hard to develop specific problem-posing skills. (9) Since the students clearly own the problems, they can realize that other problems have ownership too. Yet, they may have difficulty judging how hard a problem is; and may inadvertently reinvent problems. (10) This is a good opportunity for students to express their own cultural identity in a problem statement. Yet, they may be conditioned to imitate what they have seen in textbooks. (11) The teacher can select appropriate problems for tests based on collected student-posed problems. Yet, they may not represent what the students actually know. (12) Life skills include: inventing, designing, and teaching. Yet, (math) teachers rarely pose problems themselves; indeed, there are not many opportunities to do actual problem posing in the real world.

Reference: See [6] for an introduction to Problem Posing at about middle school level mathematics.

Incubation Mode

Synopsis: Students consider a problem over an extended time period. They work on it off and on, whenever *their interest* arises or after their ideas have developed.

Advantages and Disadvantages:

(1) This mode is easy to accommodate because it puts a problem on a "back burner" and moves problem solving out of the classroom. Yet it's a big change of pace from typical (next-class) deadlines. (2) Students can use resources from the Internet and personal calculators/computers whenever and wherever they are available. Yet some students don't have convenient access to such technology. (3) Incubation is well-suited for an untimed test or large projects which require ample time; the teacher can show trust in students. Yet, undisciplined students may not get mobilized (until the last minute). (4) Students can work in surges, get to know the problem well, and seek multiple solutions. Yet, procrastination is common, and there is no guarantee the problem will be solved. (5) Slow pace allows careful, rigorous thinking: errors die out; students can form mental connections; and subconscious creativity can blossom. Yet, real-world distractions may cause students to forget the problem. (6) With no pressure to solve the problem right away, students can relax and release their negative emotions. Yet, it is frustrating for those who feel they can't do it and aren't making progress. (7) Students may interact with others if they wish. However, if they don't, they won't get help or feedback. (8) Students are given time to develop understanding naturally (like a seed germinating). Yet, students may not be self-motivated to dig in and learn the necessary content. (9) There is plenty of time for reflection here. Yet, students are conditioned to get "the answer" and reach closure; misconceptions deepen with time; and the problem can become haunting. (10) Students can appreciate how valuable other perspectives are -- especially when they are stuck for a long time. Yet, they may not seek help outside of class anyway. (11) After Incubation mode concludes, the teacher can determine which students really can't do the problem and what needs to be taught or reinforced. Yet, this mode doesn't benefit quick problem solvers. (12) Life skills include: patience, perseverance, responsibility, and time management. Yet the real world often imposes short deadlines.

Reference: See [7] for relevant articles on insight in science and creative problem solving.

Computer Mode

Synopsis: Students use (micro)computers or calculators directly to solve a problem. This may involve software tools such as: programming languages; mathematical software packages (e.g., *Mathematica*, *Maple*, *Derive*, *Mathlab*, *Mathcad*); spreadsheets; graphics utilities; simulation and modelling "applets"; courseware; or, intelligent tutoring systems.

Note: If there are enough computers/calculators, each student may work alone—or better yet, in pairs; otherwise, they should be distributed as equally as possible.

Note: Computers/calculators can be used as tools in many other modes as well.

Advantages and Disadvantages:

(1) This mode could be used in a traditional classroom if students have calculators or lap-top computers. Otherwise, use of a computer-equipped classroom or laboratory must be arranged. (2) Modern technology is utilized -- particularly, powerful software. Yet, some students and some teachers oppose such heavy reliance on technology for teaching. (3) The teacher is free to observe, diagnose, and guide. Yet, the teacher may have to teach computer/calculator skills too. (4) Computers offer awesome number-crunching power. Yet, there are many distracting computing issues, such as temptingly easy exhaustive solutions and unexpected roundoff errors. (5) Computer work can be mentally stimulating and endlessly challenging; it can prompt students to elevate their thinking during problem solving by using results of computations which don't require thinking. Yet, this entails large cognitive overhead; and students may not know how computations are actually done. (6) Computers can be exciting, enjoyable, and empowering; this can build students' motivation for using them. Yet some students and teachers are computer phobic; others are unsympathetic computer addicts. (7) Computers offer immediate, accurate, and objective feedback to students; they can serve as a third-party arbiter in discussions of problem solving. Yet, computer interaction is essentially limited to formal language and pre-programmed responses. (8) Computer skills are in demand today; there is much to learn about computers. Yet, maybe there is too much, with little relation to mathematics and problem solving; computing is rarely integrated into curriculum; and computer manuals are notoriously bad for learning. (9) Students take pride in their computer competence. Yet, some prefer playing computer arcade games. (10) A "computer culture" can arise among computerphiles. Yet, other students may ostracize them as "computer geeks." (11) Computer skills can enhance students' math performance. Yet, evaluating these interrelated skills is complicated. (12) Life skills include: computer literacy, computer applications, and computer careers. Yet mathematical programming has become a specialized skill in this technologically developed age.

Reference: See [8] for an early vision of personal computers in education using Logo.

Paired Mode

Synopsis: Pairs of students work together as partners to solve a problem.

Note: This mode is designed without specific roles here in order to allow the students to decide how best to optimize their efforts.

Advantages and Disadvantages:

(1) This is distinctly different from traditional lecturing and individual mode. It's noisy, takes extra time, and may involve some re-arrangement of classroom furniture. (2) Paper/pencil may be adequate, so advanced technology may not be needed. (3) Students can teach each other what they know. Yet, they may not know enough and may convey misconceptions. It's hard for the teacher to monitor all students, and matching partners can be troublesome. (4) Paired mode essentially doubles a student's chance of solving the problem: when one student is stuck, the other can help; they can check each other's work, help keep focused on the problem, and seek better solutions. Yet, individual problem-solving style is compromised; one student slows down the other. (5) "Two heads are better than one" — students exchange ideas, as explaining sharpens the mind. Yet, it's hard to think and talk or listen at the same time. (6) Many students like working together, which reduces their fear of problem solving alone, and may feel more comfortable without the teacher watching. Yet, some students don't know how to collaborate well; and personality conflicts can spoil things. (7) Most students love to talk; this mode gives them "airtime"; they can explain their problem-solving approach and get immediate feedback. Yet, some students' explanatory skills are undeveloped. Some lack social skills or get off task easily while some prefer problem solving independently. (8) Students can use each other as resources; discussion can provoke learning and one can teach the other. Yet, students may unknowingly mislead each other; and it's hard to take notes while cooperating. (9) Students must develop and use a common representation so that the problem becomes "theirs." Yet, ownership of ideas gets blurred quickly. (10) Students have a good opportunity to exchange perspectives and to notice differences in language, customs, etc. Yet, they may be unable to work together because of cultural differences; or, they may be more interested in getting to know each other than in problem solving. (11) It's a lot easier to say "we failed" than "I failed." Yet, a "hitchhiker" is unfair to the better student; it's hard to separate individual contributions. (12) Life skills include: cooperation, communication, willingness to compromise, and

interpersonal sensitivity. Yet, students will often be on their own problem solving in the real world.

Reference: See [9] for an article on fostering basic problem-solving skills, including a protocol of a pair of remedial freshmen mathematics students.

Think Aloud Mode

Synopsis: Two students are given a problem and take on specific roles. One student is the "Solver." The other acts as a "Recorder." The Solver's role is not only to work on the problem, but also to explain his/her thinking—aloud—as s/he goes along. The Recorder's role is not only to record the Solver's work, but also to encourage the Solver to articulate his/her thoughts, to keep him/her focused on the problem, and to review aspects of the problem-solving activity whenever the Solver wishes. However, the Recorder is not permitted to give substantive hints nor to join in actually solving the problem. Then, the same two students switch roles and are given a different problem.

Advantages and Disadvantages:

(1) This is a variant of PAIRED mode. It has not been used much in mathematics education (to date), so students are not used to it. There is not enough private space in a typical classroom; it can be annoyingly noisy or deathly silent. (2) Audio-tape or video-tape can be very helpful here. Yet, playback of tape recordings is awkward during actual problem solving. (3) Formal roles keep students on task. Yet, many students don't like the rigid roles. (4) Both students must focus on problem-solving processes instead of getting the answer. Yet, articulating thoughts interferes with solving the problem; and, there is no substantive help for Solvers. (5) Solvers can check their own thoughts in preparing to speak; Recorders get a 'live' window into Solvers' thinking. Yet, this violates the Solvers' private cognition; and it's hard to explain one's thoughts anyway. (6) The Recorder's presence validates the Solver's efforts and can provide empathy for Solvers performing under pressure. Yet, Solvers may feel self-conscious, intimidated, or worried about being correct; Recorders may feel uncomfortable watching someone struggle. (7) This mode requires 'math talk' as Solvers articulate their problem-solving processes; and well-defined roles prevent one student from dominating. Yet, the roles are unnatural, are not cooperative, and can be overwhelming. (8) Recorders can develop listening skills and learn from Solvers; Solvers can understand their own problem solving better. Yet, Recorders may be too busy monitoring to learn much; and Solvers are focused on solving the problem, not learning *per se*. (9) The Solver must own the problem; both

students must reflect on their thinking and problem solving. Yet, most Solvers are reluctant to air dirty cognitive laundry and may distort things. (10) Students can appreciate how problem solving differs due to language, customs, etc. Yet, they may be deterred by extreme cultural differences. (11) This mode can be used as an alternative assessment tool; a detailed transcript (protocol) of the Solver's problem-solving process is a valuable reference. Yet, it's hard for the Recorder to write everything down accurately and time-consuming to analyze it. (12) Life skills include: explaining, listening, note-taking, carrying out responsibilities, and performing under pressure. Yet, nobody solves math problems like this in the real world.

Reference: See [10] for a close variant of this mode where one student is an "active listener."

Interviewing Mode

Synopsis: Two students interview each other soon after working on a problem (in some other mode). By asking probing questions, the interviewer tries to find out the important and interesting aspects of how the interviewee solved (or attempted to solve) the problem. Then they switch roles.

Advantages and Disadvantages:

(1) This mode is novel, refreshing, and quick. Yet it must be coordinated with a previous mode using the same problem; and classroom space must be re-arranged somewhat to pair students up out of close hearing range. (2) It is suitable for audio- or video-taping, which is valuable to review. Yet, the presence of a microphone or camera can inhibit some students. (3) Interviewing is a good opportunity to review and reinforce problem-solving skills; it gives students significant "authority." Roles keep students on task, and emphasis is on processes, not answers. Yet, if the interview is a rehash, it just wastes time. Students tend to socialize and it's hard to keep them on task with so little teacher control. (4) Students get a second look at the problem—a chance to correct mistakes, get unstuck, improve their solution, and consider related problems. Yet, they may just dwell on what they have already done. (5) Interviewees must describe their thinking, organize their thoughts, and can refine their reasoning, rethink their approach or get new insights; interviewers must focus attention on the problem and get a window into problem-solving processes. Explanations increase understanding for both. Yet interviewees may hide failures or distort the story and forgetting happens! (6) Interviewees can enjoy revisiting familiar work with confidence; interviewers can validate their efforts. The safety of roles allows students to express their feelings about problem

solving openly (and perhaps therapeutically). Yet, interviewers may be insensitive; interviewees may be uncooperative or competitive or worried about sounding stupid. (7) This mode is inherently interactive; students can present their best work to a captive audience, verbalization makes problem solving explicit, and students can talk in their own language. Yet, it may seem unnatural to 'talk math'; some students are reluctant to verbalize while most students lack interviewing skills. (8) Both students can learn skills and knowledge from each other. Yet, they may exchange misinformation: the interviewee may fake an explanation and the interviewer may not learn much. (9) Required reflection can clarify problem solving processes for both students, spawn multiple representations as a basis for comparison, and help them better judge how hard the problem is. Yet, interviewees might become idiosyncratic or obsessed about the problem, and interviewers may not really care. (10) An interview is a good opportunity to draw out the larger context of problem solving. Yet, students may not include cultural aspects unless prompted. (11) The teacher can also interview the students (afterwards). Otherwise, it is hard to assess individual contributions. (12) Life skills include: preparation, accountability, conversing, explaining, listening, interpreting, questioning, and "thinking on your feet." Yet, opportunities for interviewing in the real world are rare.

Reference: See [11] (Chapter 12) for suggestions on where and when to use interviewing in elementary mathematics.

Gaming Mode

Synopsis: Students play a mathematical game with different partners, develop strategies, and discuss them with each other.

Advantages and Disadvantages:

(1) This mode is a good change of pace; particularly good for a Friday. Yet, it takes time; it requires additional materials and possibly some re-arrangement of the classroom. (2) Students can play against a computer at various levels of difficulty. Yet some would rather play person-vs-person. (3) Gaming is a good pedagogical "ice breaker" for a first class and a possible equalizer for less-mathematically inclined students. Yet, it's unsuitable for immature students. (4) Students must apply their problem-solving skills in a game context; there are interesting problems and numerous challenges to consider. But where's the math? And, how does gaming fit into the curriculum? (5) To think strategically, students must analyze patterns, use if-then logic, and look ahead in a game tree.

Yet, conceptualizing strategies can be hard: some students just guess and hope, some get mental blocks; some misinterpret the rules or don't read the directions. (6) Playing games can be fun. Students can build tolerance for intellectual competition: winning builds confidence while losing can motivate students to improve. Yet, losing can be painful and may lower self esteem while winning can undermine personal relationships. Negative emotions arise from the pressure to make a move—notably fear of failure, performance anxiety, and reluctance to compete. (7) Games are inherently interactive and engaging; they involve hands-on activity and possibly hand-eye coordination; students can express and discuss their strategies. Yet, sometimes this makes students rowdy or tense or bored; competition can discourage talking. Gaming may be unproductive when either player is inexperienced or disinterested, or when opponents are mismatched. (8) Players learn experientially, get immediate feedback in context, and learn from mistakes. Indeed, losing provokes learning, winning reinforces understanding, and practice leads to improvement. Yet, there may be too much to learn in too little time; to play well can be an overwhelming, unrealistic task. (9) Students must consider what worked, what didn't, and what to do next; they can reconsider critical situations, judge levels of difficulty, and invent related games; and there is inevitable comparison with other students. Yet, students are all too often obsessed with winning; such egoistic meta-thoughts can override thinking about game strategy. (10) This mode is a good opportunity for the teacher to introduce the cultural history of the particular game and to recognize expert players from around the world. Yet, students may be more interested in games their close friends play. (11) Gaming is a potentially good diagnostic tool. Yet, it is difficult to discern what mathematical problem-solving skills are embedded in games. (12) Life skills include: competition, quick decision-making, responsibility for decisions, respect for good players, participation in game communities. Yet, gaming is controversial because of its association with gambling, entertainment, competitive sports, and military violence. It's not usually welcome in schools. Many people don't like competition, and few math games represent the real world.

Reference: See the introduction of [12] for a succinct rationale for developing deductive thinking and related problem-solving skills through an instructionally rich game.

<u>Small Group Mode</u>

Synopsis: Groups of three or four students work together cooperatively on a problem.

Note: This mode may also be called "Cooperative Problem Solving" or "Collaborative Problem Solving."

Advantages and Disadvantages:

(1) This mode is a distinct contrast with traditional lecturing and individual mode. It's noisy, takes time, and may involve some re-arrangement of classroom space. (2) Low technology (paper and pencil or chalkboard) may be adequate. Yet, computer technology would bring a competing authority into the group. (3) Students can manage themselves; the teacher can circulate as a "guide on the side" (instead of "sage on the stage"). Yet, it's difficult to form effective groups, hard to monitor students unobtrusively, and awkward to change groups. (4) Small Groups increase each student's chances of solving the problem; everyone has a common goal and can help each other. Yet, students don't work at the same rate; some slack off, and grouping smothers individual problem-solving styles. (5) Students can exchange ideas with each other, build on ideas, go with best idea, check each other, and uncover misconceptions; and re-think their approach. Yet, confusion can arise from conflicting thoughts: it may slow down the better student(s) and it's hard to think and listen at the same time. (6) Many students like working in groups because it reduces pressure; they feel mutual support and have confidence that someone (else) will know what to do. If the group succeeds, all students feel good. Yet, some students don't like groups and just want to solve the problem by themselves; there can be negative tension, strife, competition, pressure to agree, and worry about other students' put-downs. (7) This mode creates "airtime" for students—a chance to talk, be heard, get immediate feedback, and make decisions together. Yet, group dynamics can be explosive due to personality conflicts: two can gang up on one; one can dominate. Furthermore, students' verbal skills may be undeveloped, conversation may get disjointed or too social, students may be uncooperative or lack leadership, and it's not usually easy to reach consensus. (8) Students can learn actively from their peers, different explanations provide more chances for understanding, and it's hard for any one student to hide. Yet, students' abilities differ, students may spread misinformation, and it's awkward to take notes. (9) Students can compare attitudes, thinking, and proposed solutions. Yet, they may be too busy for much metacognition. (10) Students can share their cultural perspectives naturally. Yet, this may be dismissed if it doesn't contribute to solving the problem. (11) The group must produce a mutually understandable representation of the problem and possible solutions; group pride can emerge. Yet, it's hard to separate group and individual accountability; group work may be unfair to better students. (12) Life skills include: cooperation, listening, explaining, non-verbal communication, compromising, consensus decision-making, and interpersonal relationships. Yet, some people don't work well in groups in the real world.

Reference: See [13] for a handbook on cooperative learning in college mathematics education.

Coaching Mode

Synopsis: Students or teacher aids are designated to coach teams of about five students on how to solve a certain type of problem. The coaches try to ensure that everyone knows how to solve such problems. Then teams are given a problem to solve within a time limit, and one student is called on to represent the team in a competition comparing solutions. Afterwards, the coaches review solutions with their teams.

Advantages and Disadvantages:

(1) This mode utilizes selected students or teaching aids as resources; it has a manageable group size. Yet it is noisy, difficult to monitor, time consuming, and may need some classroom rearrangement. (2) An overhead projector, chalkboard, or computer can be used for display of instructional information. Yet, paper handouts may be sufficient. (3) Intensive peer tutoring is good for review; it gets students' attention and encourages everyone to work. Students are in control, and the special role of "coach" allows students to be "expert for the day." Yet, extra effort is required to train coaches: a coach may not have good teaching skills; the team may not accept the coach; and, there is no direct instruction by the teacher. (4) The coach can help motivate students who are stuck. Yet, there is no help during problem-solving competition, and no guarantee that the team will solve the problem. (5) It helps students get into a good frame of mind and be mentally focused. Yet, thinking gets narrowed: there may be too much information at once and students tend to cram instead of understand. (6) Peers can offer moral support for each other as team members; there may be more willingness to take risks with peers; and competitive instincts can be channeled into team spirit. Yet, it's inherently competitive and stressful. There is a lot of pressure on the coach whose weaknesses may get exposed: the coach may be insensitive, uncommunicative, overwhelmed, or otherwise bad. (7) Students get immediate feedback and help from peers; explanations are in student language. Yet, not all students may actually contribute to the team interactively. (8) Students learn best when they have to teach. As a coach, one can freshen up skills. Indeed, a coach does extra work and must know the content well; actually, it's a knowledge-rich experience for all. Yet, the coach may convey misinformation; so the teacher must rectify things later. (9) In order to prepare, the coach must reflect on mathematical content, consider students' different ways of thinking, recognize others' strengths, and may uncover misconceptions. Yet, the teacher may be

biased in selecting coaches and team comparisons may be embarrassing. (10) This mode is a good equalizer if all students get a turn to be a coach. Yet, students may reveal prejudices about who is qualified. (11) The teacher can observe some students' performances publicly and review coaches' notes afterwards. Yet, it's easy to blame failure on the coach. (12) Life skills include: teamwork, responsibility, leadership, competition, study skills, coaching, teaching. Yet, beware prolonged dependency on a coach.

Reference: See [14] for a discussion of an apprenticeship system for coaching problem solving. Also see www.mathcounts.org for a program for training school teachers to coach "mathletes" in mathematics competitions.

Brainstorming Mode

Synopsis: In groups of about seven, students generate ideas for solving a problem (or designing a math project). Specific roles are assigned: Moderator, Recorder, Purger, Timekeeper; and, everyone is an Idea Generator. Emphasis is on creative imagination and no criticism is permitted. Ideas are then categorized, evaluated, selected, and implemented.

Note: Groups may pool ideas and may implement them using a different mode.

Advantages and Disadvantages:

(1) This mode is quick and does not require access to resources (other than students' brains). Yet, it is very noisy; and a large board is needed to display ideas. (2) Audio- or video-tape can relieve the burden of taking notes. Yet, it's awkward to replay tape during brainstorming. (3) It is refreshing, energizing, and a good 'starter'; roles help control student behavior. The teacher may participate. Yet, Moderator and Recorder roles are very demanding; students may burn out quickly. Flights of fancy are not usually welcomed in the classroom. (4) This productive idea fest yields many diverse options which may lead to multiple solutions; students can build on each other's ideas. Yet, some ideas may be outrageous and unusable. Good students may get distracted. It's tempting to try solving the problem before generating more ideas. (5) Brainstorming opens the mind and encourages creative thinking "outside the box"; it challenges assumptions and counters the typical tendency to go with the first idea. Yet it can be chaotic and confusing: too much, too fast; and, possibly misleading as a license to think irresponsibly. (6) It's low risk and fun, students can feel

positive about their contributions, there are no wrong answers, everything is accepted, and "disenfranchised" students may rise to the occasion. Yet, it may be intimidating for shy students; some worry that their crazy ideas may get ridiculed; others may feel hurt when theirs get ignored. (7) This mode sparks spontaneous and intensive 'math talk'; everyone can participate freely. Yet, it's a verbal frenzy, with interruptive style and extroverts dominate. (8) Students can hear a variety of approaches to problem solving. Yet, they can't get explanations right away, and there is no guidance for learning how to be creative here. (9) Students collectively own the results; connections can be emphasized in a "knowledge web." Yet, it's hard to detect good ideas; indeed, there is no check against bad ideas, no way to correct misconceptions, and no time for metacognition while generating ideas. (10) This is a great opportunity for students to express diverse perspectives safely. Yet, there is no guarantee that students will honor cultural values. (11) The Recorder produces a record of the group's ideas. Yet guidelines are needed for assessing individual students' contributions. (12) Life skills include: "lateral thinking," fast thinking, valuing others' ideas, workplace applications (e.g., product design, advertising, management). Yet, brainstorming is not used productively often enough in the real world.

References: See [15] for an early introduction to "lateral thinking" and write Perfection Learning, 10520 New York Ave., Des Moines, IA 50322 for deBono's CoRT Thinking lessons which are available to schools. Also, see www.mindtools.com/brainstm.html for an intoduction to brainstorming, and other leads.

Family Mode

Synopsis: Each student is given a problem to work on and share with parent(s), caretaker(s), sibling(s), or other family member(s) or friend(s) at home. The student observes their efforts, records their work, and compares it with his/hers.

Advantages and Disadvantages:

(1) Students can work on their own schedule outside the classroom. Yet it's hard to find time; and they may impose on family/friends' routines. (2) Students can use technology available at home. Yet, low-income families can't afford computers. (3) This "homework" is a unique opportunity to do math with family/friends; they can help teach the student and appreciate the need for mathematics education. Yet, complex psychological factors are involved; some families/friends are

dysfunctional and activities are beyond the teacher's control. (4) Students can see how someone else tackles the problem; this helps sustain their interest; and they get several chances to solve it. Yet, there may be very different levels of math ability: the family/friend may not be able to solve the problem at all; or, a mathphile family/friend may spoil it for the student. (5) There are different sources of ideas. Yet, family/friends' minds may be too similar. (6) A familiar emotional environment allows more risk-taking; bonding may occur. Yet, past emotional baggage may inhibit risk-taking: the family/friend may be uninterested or mathphobic, or may ridicule the student; and, arguments, stress, and sibling rivalry may erupt. (7) This mode draws on established relationships, with no language/cultural barriers, and allows intimate discussion; it calls for "quality math time"; students get individual attention, help, honest feedback, patient explanation, and a natural way to follow up. Yet, it may be hard to get family/friends to participate. The family/friend may know math but can't explain it well or might dominate interaction; and, feedback may be too painfully honest. (8) This is a special opportunity to learn skills and knowledge from family/friends and vice versa; it might help build a learning community. Yet, the family/friend may be a bad model; and beware distractions, excuses, and an anti-math home learning environment. (9) The student and the family/friend can contrast their solutions, discuss how hard the problem is, and take pride in mutual accomplishment. Yet, a competitive comparison may be counterproductive. (10) It is certainly a good opportunity to bridge college and home cultures. Yet, the students' family/friends may prefer keeping them separate. (11) The teacher gains another basis for assessment. Yet, it is not objective: How much help did the student get? (12) Life skills include: family-teacher-student relationships, listening, explaining, and valuing lifelong learning. Yet, this is a very controversial mode; old wounds can be opened which might provoke need for therapy.

Reference: See [16] for a university-based project to involve families in math and science education.

Large Group Mode

Synopsis: A large number of students work on a problem at the same time, with leadership from the teacher who calls on students to contribute ideas and assists them toward solutions.

Note: "A large number" may be twenty to thirty students in a stereotypical classroom, to hundreds in a lecture hall, or even thousands in a virtual classroom via the Internet "distance education."

Note: This mode is "problem-based" whereas in traditional lecture mode background, information is usually presented first.

Advantages and Disadvantages:

(1) This mode is efficient for teaching many students problem solving at the same time; if the classroom is already arranged for a large group, no changes are needed. (2) It is well-suited for a chalkboard, overhead projector, or computer displays for demonstrations, simulations, websites, etc. Yet, such technology must be set up in advance. (3) It's a teacher-centered format, engaging the whole class in collective problem solving; it's good for observing students, collecting data, and modeling effective problem solving; and, there is equal opportunity for all students to contribute. Yet, student participation is bottlenecked through the teacher; it's impossible to bring all students up to the same level; discipline problems can arise. It is an overwhelming job. (4) This mode maximizes chances of solving the problem in minimal time: there is a common goal, many possible approaches, and potential synergy. The teacher can guide students toward multiple solutions. Yet, a mob approach can compromise individual problem-solving style, and students may mislead each other. (5) The teacher can stimulate students' thinking, pool their thoughts, build on their ideas or create "cognitive dissonance." Everyone has the right to check each other; argumentation can be beneficial, and the teacher can correct misconceptions immediately. Yet, there may be too many different ideas, different rates of thinking, or mass confusion; it's hard to hold thoughts in mind and some students tune out. (6) A large group is common for lecturing where students can listen and observe safely. Yet, it's risky to speak up. Students may fear ridicule by other students or the teacher; or, they're quickly frustrated when they can't get a word in. (7) Interaction relies on conventional hand-raising. Confident, verbal students can excel; some develop public speaking skills. Yet, there is limited "air time": a few students can dominate while passive students get shut out; side conversations are disruptive; and there may be too many voices—or a deadly silence. (8) Students can watch, listen, and decide what to learn from the teacher and other students. But it's easy to rely on others to do the work and not learn much. The teacher must correct students' misinformation, which slows down better students. (9) Students tend to compare themselves with others, which may motivate them. Yet, some may be reluctant to reconsider their problem-solving approach; the teacher may misinterpret or misphrase a student's idea publicly. (10) Students get to hear many other students' perspectives; and the teacher can add cultural background about the problem. Yet, some students may not appreciate more information which does not directly help solve it. (11) The teacher has a good vantage point to spot strong students. Yet, it is difficult to assess individuals' contributions which piggyback on others and to detect if those who don't

contribute at all had good understanding (and, therefore, teachers may have to rely on individual reports anyway). (12) Life skills include: public speaking, listening, patience, consensus-building, communal problem solving. Yet, real-world problem solving is not usually done in a large group.

Reference: See [17] for how the process of group problem solving through discussion is essential to democracy.

Presentation Mode

Synopsis: The teacher presents relevant problem-solving skills and mathematical knowledge along with an illustrative problem while students listen, take notes, and ask questions. Then the teacher demonstrates how to solve the problem. Later, students practice solving similar problems (for homework) and present their solutions (in the next class).

Advantages and Disadvantages:

(1) This mode is efficient for disseminating a lot of information to all students in the same place at the same time. Yet, the classroom (furniture) must be arranged accordingly for an audience. (2) It is well-suited for using technology to enhance teaching with traditional chalkboard, overhead projector, film, video, or computer display system (with presentation software) and Internet connection. Yet, it involves setting up equipment in advance, and some students resent technology which allegedly de-personalizes teaching. (3) It is a strongly teacher-controlled mode for introduction or review of specific skills and knowledge; there is equal opportunity for all students to learn the same information. Yet, it is usually paced for the "average student." (4) Students are given a solution template for solving a certain type of problem and can practice solving similar problems. Yet, this may be a crutch which doesn't help them solve other (non-routine) problems. (5) Students get to hear the requisite vocabulary before attempting to solve a problem; a dynamic presentation stimulates thinking. Yet, few students can think during a presentation dense with information; boredom is likely. (6) Students are familiar with lecturing. It's easy for them to hide; public put-downs by the teacher or peers can damage self-esteem. (7) Students can listen, ask appropriate questions, and develop public speaking ability. Yet, there is little "air time" for each student. (8) Students are told what skills/knowledge are needed for problem solving. Yet, rote practice does not guarantee conceptual understanding. (9) Students own their presentations. But, they don't own presentations by the teacher. (10) The teacher can take the opportunity to point out cultural

perspectives on problem solving. Yet, it may be difficult to integrate different perspectives. (11) This mode is convenient and fair for testing students who have been presented the same information. Yet, assessing their presentations is complicated by stage presence. (12) Life skills include: listening, note-taking, questioning, public speaking. Yet learning "on the job" is not like this.

Combinations of Modes

These modes may well be combined; indeed, there are many potential combinations of only two or three modes. For example: Small Groups reporting back to the Large Group; Individual work then Interviewing; Exploration then Paired problem solving; Small Groups then "jigsaw" Small Groups (re-formed with one student from each); Gaming with Think Aloud about strategies; Paired students in Computer mode; Brainstorming ideas, then implementation in Small Groups; Family sharing, then Presentation; Incubation, then Coaching; Exploration, then Problem Posing, then Individual problem solving. See [2] for details.

Other Modes

Other possible modes include: EXPERT mode, in which students observe an expert solving problems in a "cognitive apprenticeship" [18]; SILENT mode, in which the teacher shows students how to solve a problem without saying a word -- using only diagrams, body language, and writing in response to questions; PERSUADE mode, where a small group works on a problem, then presents their solution to another small group, trying to persuade them that they have solved the problem [19]; PYRAMID mode, in which students work on a problem individually, then pair up, then join in two pairs, then brainstorm in a group of eight, then combine results in a large group with the teacher; INTERNET mode, in which the teacher posts problems on an on-line bulletin board and/or e-mails problems to students who work on them collaboratively via e-mail distribution lists and/or chat rooms, and then post their results for critique by the teacher and other students. See [2] for details.

General Advantages and Disadvantages

Overall, the modes presented here offer some general advantages, balanced by intrinsic disadvantages: (1) Teachers can choose alternative modes (or combinations of modes) which fit best within the practical constraints of their particular situations. Yet, choices are limited by the classroom space, time available, and existing resources. (2) Technology provides powerful tools for enhancing teaching and learning. Yet, it incurs extra costs, technical difficulties occur, and training and additional effort are required. Some teachers distrust technology and it may also distract students away from mathematics. (3) Teachers can choose modes which are compatible with curricular content, suit their philosophy or teaching style, and motivate students. Yet, a new mode may cause a "Hawthorne effect" (getting their attention just due to a change). (4) The mode should increase the students' chances of solving the problem. Yet, it does not guarantee they will actually solve it. (5) The mode should enable students to do more productive thinking. Yet, their minds may become overloaded or distracted by new activities. (6) Making students emotionally comfortable should reduce math anxiety. Yet, anxiety may increase when they have to change their usual routines. (7) Interactive student communication can help problem solving and learning. Yet, it may increase confusion; and, there are always language barriers. (8) Some students learn problem-solving skills and knowledge better in certain modes. Yet, they may not learn well in all modes; and there is no guarantee of transfer from one mode to another. (9) Students can become more aware of their own problem-solving processes manifest in different modes, judge how well they are progressing, and compare their performance with their own expectations or with other students'. Yet, they may be reluctant to confront what they know vs. what they need; and, it is hard to do problem solving and metacognition at the same time. (10) Problem solving in different modes can help students respect individual differences and appreciate multicultural perspectives. Yet, it may conflict with practices within their family or local community; and it may raise complex issues about gender, race, special needs, etc. (11) Students' reports provide a record for both formative and summative assessment. Yet, it may be hard to get students to write reports; and some students dislike peers influencing their grades. (12) These modes allow development of life skills. Yet, many students have short-term interests.

General Issues and Recommendations

A number of general issues pervade all these modes, including: how to evaluate the mode; changes in the teacher's role; how to choose a mode to match a given problem; how to choose an appropriate problem to match the mode; how to group students or accommodate their differing abilities; how to assess students' work; how to deal with students' non-participation, avoidance of learning, cheating, and other discipline problems. Since these issues are beyond the scope of this article, they will not be addressed here.

A general recommendation for mathematics teacher educators is to arrange for prospective and/or in-service teachers to try out these modes themselves (acting as students) in a course, before using them in school classrooms.

Recommendations for teachers:

- Choose a mode which maximizes your purposes (but don't rely on it alone to fulfill all purposes).
- Explain the mode and model it for students before using it.
- Use a mode by itself before combining it with another mode.
- Practice the mode several times before evaluating it.

Feedback

These modes have been introduced to math teachers at elementary, middle-school, secondary, and higher education levels as part of a graduate course offered at University of Massachusetts' School of Education for the past ten years. About 100 teachers personally tried out each mode, informally field-tested most modes in their own classrooms, then critiqued all modes and discussed issues related to mathematics education reform.

Although these modes were not formally evaluated, feedback from teachers generally indicated that they welcomed alternative modes (and combinations) for vitalizing their teaching, that different modes enabled them to meet different students' needs, and that, while most modes are time-consuming, the actual advantages usually outweighed any disadvantages.

Hopefully, mathematics teacher educators will encourage teachers to consider adopting and adapting these and other effective modes in order to help students become better mathematical problem solvers. ■

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Bio

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ACTIVE LEARNING IN SOPHOMORE MATHEMATICS: A CAUTIONARY TALE

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Math 245: Multivariate Calculus, Linear Algebra, and Differential Equations with Computer I is the first half of a year-long sophomore sequence that emphasizes the subjects' interconnections and grounding in real-world applications. The sequence is aimed primarily at students from physical and mathematical sciences and engineering. In Fall, 1998, as a result of my affiliation with the Science, Technology, Engineering, and Mathematics Teacher Education Collaborative (STEMTEC), I continued and extended previously-introduced reforms in *Math 245*, including: motivating mathematical ideas with real-world phenomena; student use of computer technology; and, learning by discovery and experimentation. I also introduced additional pedagogical strategies for more actively involving the students in their own learning—a collaborative exam component and in-class problem-solving exercises.

The in-class exercises were well received and usually productive; two were especially effective at revealing normally unarticulated thinking. The collaborative exam component was of questionable benefit and was subsequently abandoned. Overall student performance, as measured by traditional means, was disappointing. Among the plausible reasons for this result is that too much material was covered in too short a time. Experience here suggests that active-learning strategies can be useful, but are unlikely to succeed unless one sets realistic limits to content coverage.

Introduction

The typical full menu of sophomore-level math consists of separate 3-hour, semester-long courses in multivariable calculus, linear algebra, and differential equations. Ordinarily, those courses follow the traditional approach: mathematical concepts and techniques are presented—often in a dogmatic way with little motivation—and illustrated, and only then are they applied; the students solve problems not dissimilar to examples they have already seen in the text or in lecture; and, the problems often require technically complex algebraic manipulations.

Nearly a decade ago, my former colleague, Frank Wattenberg, integrated these three courses into an experimental, year-long sophomore sequence of two 4-hour courses, for which he privately published a new text in three volumes (1999-2000); he also designed parallel web-based materials [1]. The two courses formed a sequel to Wattenberg's experimental freshman calculus course based upon materials that became his text *Calculus in a Real and Complex World* [2].

These experiments were local instances of a widespread effort to reinvigorate the introductory mathematics curriculum that is generally known as "calculus reform" [3]. That effort extended to linear algebra, thanks in part to the work of the Linear Algebra Curriculum Study Group [4], as well as to differential equations, which had already begun to be influenced by the availability of differential equation solvers and graphers [5].

This article reports on my experience with the first semester of this course in Fall, 1998 when I introduced additional pedagogical strategies into the course. It necessarily discusses my experience with the reforms already then in place, because the totality of innovations in the course affected outcomes of the additional strategies.

Course Aims

The principal aims of the local sophomore-level experiment, as originally formulated by Wattenberg, and subsequently extended by me, were as follows:

- To cover nine semester-hours' content from three courses in only eight semester-hours of two courses. Condensing the content was to be accomplished primarily through the efficiencies of integrating the three subjects and avoiding existing overlaps. For example, notions about linear transformations and bases of vector spaces would be covered only once—even though used in disparate contexts—rather than twice, once in linear algebra and again in differential equations. In addition, a few standard topics deemed to be of lesser importance were to be omitted. This was the case, for example, with calculating centroids of solids by means of triple integrals and solving exact first-order ordinary differential equations.

- To render linear algebra more meaningful than the usual, potentially sterile combination of routine calculation and challenging abstraction. The idea was to draw notions about vector spaces and their linear transformations from, and in turn apply them to, situations arising in multivariable calculus and differential equations. For example, eigenvalues and eigenvectors arise from systems of linear differential equations modeling the dynamics of an age-stratified population.

- More generally, to use real-world problems to motivate the key mathematical concepts and much of the mathematical development. For example, in *Math 245* linear and affine transformations appear first in the context of two-dimensional computer graphics; vector equations of lines and planes are used to find the shadow of an object illuminated by a point light source; cross-products of 3-vectors are defined so as to measure torque; powers of matrices need to be formed in order to determine the long-term effect of a betting strategy at roulette; various qualitative and quantitative considerations about first-order differential equations are introduced in the context of Newton's law of cooling; linear systems of first-order differential equations are needed to describe oscillations of spring-and-mass systems and RLC electrical circuits.

  Note that mathematical modeling was not in itself an aim. Whereas real-world problems were used to motivate mathematical ideas, some of which were, in turn, applied to real-world situations, little attempt was made to teach students to derive mathematical concepts from real-world problems.

- To appeal to different modes of comprehension, by emphasizing visual representations and numerical descriptions, not just symbolic manipulations.

- To enliven the course by more actively involving students in the process of learning. Originally, this aim meant that some key mathematical results would not initially be formulated in full by the lecturer or textbook. Rather, experimentation and exploration in homework problems would lead students to discover such results for themselves. Eventually, when I taught the course in 1998, this aim meant also that some of the exploratory learning would occur in the classroom through in-class exercises.

- To use modern computer technology for teaching and learning in order to facilitate the preceding aims.

My Involvement

Under an Instructional and Laboratory Equipment grant from the National Science Foundation, this experimental sequence became a permanent offering, *Math 245–246: Multivariate Calculus, Linear Algebra, and Differential Equations with Computer I–II*. Over the past eight years, I have taught this course five times. In Fall, 1998, thanks to my participation in the STEMTEC Winter 1998 Workshop, I introduced additional pedagogical strategies into the course while continuing to incorporate the reforms that I had already been using in the course in earlier semesters. It is upon my experience in Fall, 1998 that this report focuses.

In Fall, 1998, there was a significant change in *Math 245* student demographics that undoubtedly affected both the success of the reforms already in place and the outcome of the additional strategies.

Like the courses that they replace, *Math 245 & 246* were taught in lecture sections of at most thirty students. As in many math courses, weekly problem sets were assigned, collected, and graded. Each semester, three exams were given: two mid-semester exams and one final exam, the latter covering just the final third of the course.

Teaching *Math 245* was hardly the first occasion on which I had incorporated innovations similar to some of those in Wattenberg's courses. For more than fifteen years in linear algebra courses I had already incorporated student use of computer technology [6]; for several semesters, my students carried out a project on Hill ciphers in which they had to learn the topic entirely on their own [7]. Repeatedly in the sophomore-junior math major course, *Fundamental Concepts of Mathematics*, and once in junior-senior topology, I minimized lecturing and devoted most class time to students' devising or presenting problem solutions.

Nonetheless, the Fall, 1998, *Math 245* was the first lower-division math course aimed primarily at non-majors in which I attempted additional strategies, such as were being demonstrated and advocated at STEMTEC workshops.

Reforms

The overall approach in *Math 245* was to motivate the mathematics by means of models of real-world phenomena. The other "reforms" in this course were the students' use of computer technology; innovations in the type of homework, format of exams, and inclusion of in-class problem-solving exercises; and, incorporation of collaborative work.

Computer Technology: The principal technology used in *Math 245* was the commercial software package *Mathematica* from Wolfram Research [8]. This package, documented in [9], is a state-of-the-art "computer algebra system" that is widely used by mathematicians and scientists for research as well as teaching. It provides integrated access to an extensive repertoire of functions through an interactive "live document" interface where input, output (including graphics), and user- or instructor-supplied text can be intermixed; its functions can be used directly, with user-supplied arguments, or combined into new commands through user-written programs. In *Math 245*, *Mathematica* was used as a computational tool in place of long or complicated paper-and-pencil calculations and, more significantly, as a means of carrying out experimentation and discovery. This package was available for, and sometimes required in, homework problem sets; it was also available for students to use in the second and third of the three exams.

The symbolic, numerical, and graphical capabilities of *Mathematica* were briefly demonstrated at the first class of the semester. Several class sessions during the following week met in a computer lab, where students worked in pairs to learn basics of the software and to apply it to some problems in linear algebra. Resources for learning *Mathematica* included a textbook [10], occasional short lessons during lecture, the program's complete on-line help, and *Mathematica* "notebooks"—interactive documents—prepared by me.

Mathematica was also used "live" in lectures to make them more interesting. For example, in the study of oscillatory solutions of second-order differential equations, the phenomenon of beats could be heard—not just represented symbolically by a trigonometric formula or visually in a graph—by evaluating in *Mathematica* the following expressions:

```
ω = 263;
middleC=DSolve[{x''[t] + (2πω)^2 x[t] == 0, x[0] == 0, x'[0] == 1}, x[t], t]
Play[Evaluate[x[t] /. middleC], {t, 0, (8/5)2π}];
beat = DSolve[{x''[t] + (2πω)^2 x[t] == Cos[2π(ω + δ)t], x[0] == 0, x'[0] == 1}, x[t], t] /. δ -> 2/10
Play[Evaluate[x[t] /. beat], {t, 0, (8/5)2π}];
```

This demonstration aroused student utterances of surprise at the appearance of the plotted oscillations, looks of delight at the sounds produced, and requests to see and hear what would happen with changes to the parameters.

For reviewing or learning more about what was covered in lecture, students were given access to *Mathematica* notebooks that contained examples whose parameters the students could freely modify and where the students could create new examples of their own. These notebooks included several adapted from Wattenberg's materials and others prepared by me [11].

Some of the topics could be learned from a website authored by Wattenberg [1] for the multi-institutional Connected Curriculum Project. This site included some valuable interactive demonstrations used in class: for example, a Java applet that illustrated the abstract notion of a line segment in a vector space—here, a space of triples of matrices—by dissolving an exterior shot of the Lincoln Memorial into a photograph of the statue of Abraham Lincoln inside.

Homework Problems: The weekly homework problems often involved experimentation, exploration, and discovery. Here are two examples:

1. Given functions $\vec{f}:\mathbb{R}\to\mathbb{R}^3$ and $\vec{g}:\mathbb{R}\to\mathbb{R}^3$, discover and derive a nice formula for the derivative of $\vec{f}\times\vec{g}$, the cross-product of the two functions. Although your formula should *not* involve coordinates, your derivation may.

This problem is already more sophisticated than what is ordinarily assigned in a traditional multivariable calculus course: it asks the student not to derive a formula already supplied by the instructor or text, but to discover a formula and to derive it. Moreover, the symbolic powers of *Mathematica* can be used to do the work of manipulating coordinate functions, beginning with the following input:

$$f[t\_]=\{x[t],y[t],z[t]\};\quad g[t\_]=\{u[t],v[t],w[t]\};\quad h[t\_]=f[t]\times g[t];\quad h'[t].$$

Evaluating this compound expression in *Mathematica* returns as its result a vector of functions of t each of whose terms is of a familiar Leibnitzian "first times derivative of second plus second times derivative of first" form. The student can then conjecture that the correct answer is $f\times g'+f'\times g$; use *Mathematica* to evaluate

$$f[t]\times g'[t]+f'[t]\times g[t]$$

and see by inspection that the result is the same as before; and even let *Mathematica* check that the two results are in fact identical by obtaining True as the result of evaluating:

$$h'[t]===f[t]\times g'[t]+f'[t]\times g[t].$$

2. Every Friday, each student at State U. goes to either Sue's Subs or Paulo's Pizzeria for a late-night snack. This Friday, 70% of the State U. students went to Sue's and the rest went to Paulo's. In each case below, what fractions of State U. students go to the two restaurants on Friday of weeks 2, 3, 4,..., 20? What happens after many, many weeks go by: Is there an equilibrium state toward which the weekly vectors of fractions tend in the limit? If so, what is it?

(a) Suppose that each week, 60% of the students who go to Sue's on a Friday return to Sue's the following Friday, whereas 40% go instead to Paulo's; and 70% of those who go to Sue's on that Friday return to Sue's the following Friday, whereas 30% go instead to Paulo's.

(b) Suppose that each week, half the students who go to Sue's return to Sue's the following Friday, and the other half go instead to Paulo's; and half those who go to Sue's return to Sue's, and the other half go instead to Paulo's.

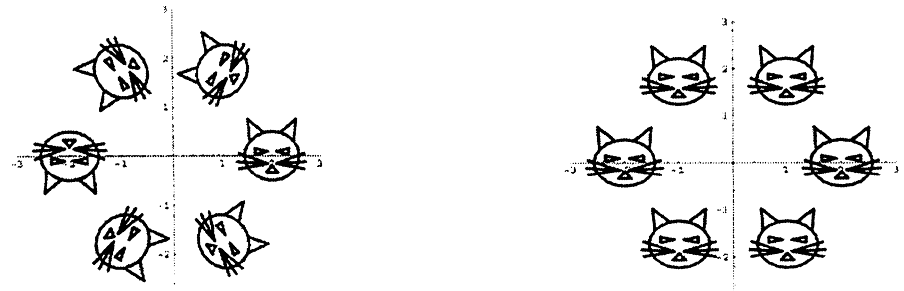
(c) Suppose that each week, all the students who go to Sue's that Friday go instead to Paulo's the following Friday; and all the students who go to Paulo's that Friday go instead to Sue's the following Friday.

This problem involves an unrealistically simple situation; other problems about Markov chains involved more realistic ones.

Homework problems often were rich—although hardly ever open-ended—and of a higher order of difficulty than is typical in sophomore math classes. For example:

3. An image of a cat's face has its nose at (2, 0). What sequence of transformations will create a movie in which the face moves counterclockwise around the origin with its nose always on the circle of radius 2? The face has to remain upright so the cat doesn't get dizzy!

Problems about composing transformations most commonly ask for synthesizing given transformations into more complex ones. Problem 3, by contrast, calls for analyzing transformations into composites of simpler ones. To solve it requires geometric insight and visualization skills and explicit formulation of a good strategy, not just a sound grasp of function composition and inversion. The crux of the cat-spinning problem is how to keep the face upright when, for a single frame of the animation, the nose is rotated through an angle θ around the origin. Some students could not figure out how to do this; the effect of their solution is as shown in Fig 1 (a). A correct solution should produce an animation whose superimposed frames appear as in Fig. 1 (b). And several different strategies led to correct solutions, including an elegantly simple one not anticipated by me.



(a) Dizzy spinning cat (b) Upright spinning cat

Fig. 1: Spinning a cat

Although they were not asked to do so, many students chose not only to describe how to create the movie, but also to realize the requisite sequence of transformations in *Mathematica* and apply them to produce an actual animation. In fact, many used *Mathematica* to experiment with their ideas and to verify whether their solutions were correct. Except for the few who made little or no progress on a solution, students were particularly engaged with, and seemed to enjoy, the cat-spinning problem. This reaction occurred despite the problem's difficulty and apparently, according to what several students said, because of the satisfaction of seeing the solution realized in action.

4. Spotted owls and flying squirrels inhabit California old-growth Douglas fir forests. The owls prey upon the squirrels. The numbers o_k of owls and s_k of squirrels in year k are related to the corresponding numbers in year $k + 1$ by

$$\begin{cases} o_{k+1} = 0.4 \quad o_k + 0.2\, s_k, \\ s_{k+1} = -0.325\, o_k + 1.2\, s_k. \end{cases}$$

Suppose initially there are 100 owls and 175 squirrels. For each k, let $\overrightarrow{x_k} = (o_k, s_k)$.

(a) Explain what the sizes and signs of the coefficients indicate about the ecological relationship between the owls and squirrels.

(b) Calculate enough entries in the $\overrightarrow{x_k}$ sequence to guess what the limit is, as $k \to \infty$, of the ratio of corresponding coordinates in successive values $\overrightarrow{x_k}$, $\overrightarrow{x_{k+1}}$; and to guess what the limits are of the ratios of each coordinate of $\overrightarrow{x_k}$. Draw informative plots of : (I) both components of $\overrightarrow{x_k}$ vs. time k; and (ii) one component of $\overrightarrow{x_k}$ vs. the other.

(c) Use eigenvalue-eigenvector analysis to help explain what you guessed to be the various limiting ratios.

Problem 4 goes well beyond what is commonly asked about eigenvalue-eigenvector analysis of a matrix: calculate the eigenvalues and associated eigenvectors, then decompose a given vector into its components in the eigenspaces. This problem has a real-world connection, and it asks for: interpreting the parameters of a discrete dynamical model; observing the model's dynamics experimentally, with *Mathematica;* and, explaining the observations in terms of eigenvalue-eigenvector analysis.

Exams: All three exams lasted at least two hours, including the mid-semester exams that in sophomore courses ordinarily take just one 50- to 75-minute period. The exams were *not* multiple choice or short-answer but rather, as is the case in nearly all our sophomore math courses, consisted of problems whose solutions were to be written out.

The first mid-semester exam was given in an ordinary classroom, and students could use their calculators. The following question is representative in its level of difficulty, its mix of the conceptual with the computational, and its combination of geometric and algebraic reasoning.

1. (a) Express reflection F across the line $x_2 = x_1 + 3$ in $\mathbb{R}^2$ as a composition of translations, rotations, and reflections across the coordinate axes. (No proof is required.)

   (b) Let L be the line in $\mathbb{R}^3$ passing through distinct points $\vec{a}$ and $\vec{b}$ and let T be translation by the vector $\vec{v}$. Use vector algebra to show that the image $T(L)$ lies on the line passing through $T(\vec{a})$ and $T(\vec{b})$.

Part (a) of this question was essentially the same as one most had solved for homework; part (b) had been a homework problem, only solved completely by some of the students. Solutions to both homework problems had been provided.

This first exam included a small-group collaborative component. During the first ninety minutes, students worked individually; their papers were then collected. By a counting-off procedure, students were then randomly assigned to groups of three or four, and during the next twenty minutes, each group gathered at a reserved section of blackboards in order to work collaboratively on the same problems. Students were then given a new, blank copy of the exam, and during the final thirty minutes, they again worked individually on any problems or parts of problems they wished. To each student's score on the original work, 50% of any improved score from the group work was added.

Whereas the other two exams involved individual work only, they were administered in a computer lab where the students could freely use *Mathematica* for symbolic and numeric calculations as well as for visualization. The first two of the following three questions are from the second mid-term exam, and the third is from the final exam.

2. Let $T : \mathbb{R}^4 \to \mathbb{R}^4$ be the linear transformation whose standard matrix representation is

$$A = \begin{bmatrix} 1 & 2 & 1 & 7 \\ 2 & 4 & 3 & 18 \\ 3 & 6 & 3 & 21 \\ 4 & 8 & 4 & 28 \end{bmatrix}$$

   (a) Find a basis of the kernel of T.

   (b) What is the dimension of the image of T? Why? Is T one-to-one? Why or why not?

3. In the following two-species population model, $p(t)$ and $q(t)$ are the two populations' sizes, in hundreds, after t years:

$$\begin{cases} p'(t) = (\ 2 - 1.2q)p, \\ q'(t) = (-1 + 0.9p)q. \end{cases}$$

   (a) What, according to this model, is the relationship between the two species—competitive, aggressive, predator/prey, or something else—and why?

   (b) Estimate the sizes of the two populations after ten years if initially the two populations' sizes are 1 and 0.5 (in hundreds), respectively.

4. *Without* using *Mathematica*'s built-in DSolve, find *all* solutions of the differential equation $y'' - 6y' + 9y = e^{3t}$.

The preceding three questions are not unlike what might be asked on a traditional paper-and-pencil-only exam—except that many traditional differential equations courses would not even reach the topic of nonlinear systems, since so much time would already have been devoted to obtaining exact solutions through symbolic manipulations. In questions 2 and 3, however, the examinees were able to avoid tedious or error-prone numerical calculations through use of *Mathematica*; in question 4 they were able to use *Mathematica* to do most of the symbolic calculations as well as to check their answers.

In-Class Problem-Solving Exercises: On average at least once a week—and most often during one or both of the 75-minute class meetings rather than during the third, 50-minute class meeting—students worked during class on problem-solving exercises. Many of these were straightforward exercises to check, on the spot, understanding of principles and methods that had just been covered in lecture or, less commonly, in the previous class or reading assignment. For example:

1. Prove that the reflection $\text{refl}_L : \mathbb{R}^n \to \mathbb{R}^n$ across a line L through the origin in $\mathbb{R}^n$ is linear. You may use the fact that the projection $\text{proj}_L : \mathbb{R}^n \to \mathbb{R}^n$ onto L is linear as well as the formula $\text{refl}_L(\vec{v}) = 2\,\text{proj}_L(\vec{v}) - \vec{v}$ derived in class.

The purpose of Exercise 1 was to establish linearity by verifying in this instance its abstract characterizing property $T(a\vec{v} + b\vec{w}) = aT(\vec{v}) + bT(\vec{w})$ rather than through concrete representation by a matrix.

2. Find all solutions of the ODE $y' = y/t$. Then find those satisfying initial conditions $y(1) = 2$ and $y(1) = 0$, respectively.

Exercise 2 was intended to reinforce the idea that equilibrium solutions of a separable differential equation had to be obtained separately, before the method of separation of variables could be legitimately applied.

Some in-class exercises were intended to guide the students to discover a principle. For example:

3. Let A be an $m \times n$ matrix. Determine $A\overrightarrow{e_1}, A\overrightarrow{e_2}$, and, in general, $A\overrightarrow{e_j}$ for $j = 1, 2, \ldots, n.$. Here $\overrightarrow{e_j}$ is the n-vector having 1 as its jth entry and 0s elsewhere.

4. Let a, b, c be constants. For what values of the scalar r is $x = e^{rt}$ a solution of the ODE $ax'' + bx' + cx = 0$?

Results such as those in Exercises 3 and 4 are key facts that are usually derived in lecture by the instructor and in the textbook. The reason for giving such exercises was that the students might better remember these facts, and understand why they are true, by having to obtain the results for themselves. There was a trade-off, however, in that far more class time had to be consumed when the students, instead of the instructor, did the work.

One extended in-class exercise involved a series of problems, with intervening short expository passages, devoted to: defining the complex number field as consisting of ordered pairs (a, b) of real numbers—with suitably defined operations of addition and multiplication; forming the correspondence between pairs of the form $(a, 0)$ and real numbers a; and, seeing that these special complex numbers and corresponding real numbers behave the same way with respect to addition and multiplication. One purpose of this exercise was to tell the "truth" about complex numbers that had been glossed over by the textbook which, like most, treated complex numbers naively as "expressions of the form $a + b\, i$". A more fundamental purpose was to provide an opportunity in class for guided learning through active reading. Unfortunately, the concepts involved are subtle; students' puzzled looks, slow progress with the exercise, and questions to me indicated that the students did not, in fact, get the mathematical point of the exercise.

Two of the in-class exercises were effective in unexpected ways. The first was done on the first day of class, and the second at a point two-thirds into the semester.

5. In a coordinate plane, draw a triangle that is not isosceles and is not in any "special" position—for example, does not have any sides or vertices on the coordinate axes. Consider the translation T of the plane by the vector $(4, -3)$ and the reflection S of the plane across the y-axis. Construct the images of your triangle under the compositions $T \circ S$ and $S \circ T$. Are the two images the same?

Exercise 5 was posed verbally rather than—as was the case with all subsequent exercises—on printed handouts. Following Wattenberg's practice, I provided each student with a marker along with a sheet of paper and a sheet of plastic printed with coordinate axes. The instructions were to draw the original triangle on the paper and a copy on the plastic; to effect the transformations by suitably manipulating the plastic; and to copy onto the paper the resultant triangle's position on the plastic. The technical vocabulary of 'translation', 'reflection', and 'vector' was not actually used, nor was the notation $\circ$ for composition—indeed, one of the purposes of the exercise was to introduce all these notions and corresponding notations. Rather, the translation was described as "move 4 units rightward and 3 units downward" and the reflection as "flip around the vertical axis"; composition was described in terms of doing first one operation and then the other. The term "image" was described in terms of the set of all the points you get as result.

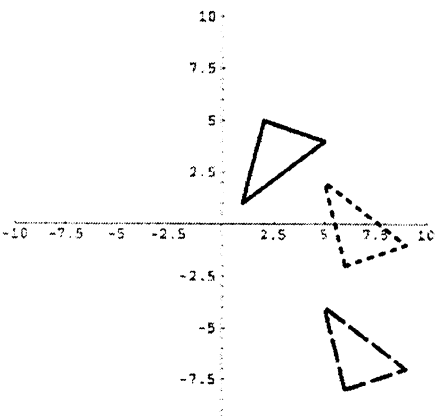


Fig. 2: Images of triangle under composition of rigid motions

The sort of configuration the students obtained is illustrated in Fig. 2, where for clarification I have drawn the original triangle with solid lines but the images with dashed lines. One of the purposes of representing the composites graphically was to allow students to realize more readily that the images are *not* the same—in other words, that composing rigid motions in the plane need not be commutative—without having first to calculate images of the vertices. Much to my surprise and seemingly despite the evidence of their eyes, many students claimed, "The two images are the same." When asked why, the students volunteered explanations such as, "The images are the same triangle as the original one, but just in different places." And, in fact, they considered each of the images in this sense as being the "same triangle" as the original one. This reaction revealed a fundamental misconception about points in the plane $\mathbb{R}^2$ and their relationship to cartesian coordinates.

What was the source of the misconception? Perhaps the notion of image was not sufficiently clear from the couple of examples, with single transformations and no compositions, that I had already presented on the board. Or perhaps the students were confused about the definition of 'same' in this context as meaning 'equal'—if not confused about the very meaning of 'equal'. Students may have been misled by their prior experience with vectors in physics or high school math, where one deliberately regards two directed line segments as being "the same" when they have equal magnitudes and directions, no matter what their locations. Maybe, too, they were misled by the practice in high school geometry of calling line segments or angles "equal" that merely have identical measure. Whatever the source of the misconception, this in-class exercise serendipitously had the effect of informing me immediately about the misunderstanding, so that I could attempt to correct it through explicit explanations and further illustrations of the concepts at issue.

> 6. When the coroner arrived at midnight, a corpse on the floor had a temperature of in the 85° F in the 65° F room. The corpse was left where it was found as the investigators went about their work. Three hours later, the temperature of the corpse had dropped to 70° F, while the room temperature still remained a steady 65° F. When did the death occur?

Problems like Exercise 6 are "old chestnuts" in differential equations. When the exercise was posed, the class had already learned about Newton's law of cooling from the textbook and in a previous lecture, but only as a model for the decay in time of a freshly poured cup of coffee's temperature. During the exercise, I circulated around the classroom, eavesdropping on group discussions and observing what was being written down. I could tell that most students recognized the relevance of Newton's law, but many were having difficulty deciding how to identify the relevant variables and constants from the given data. The students had been, as usual, encouraged to work in small groups. In one group, a member expressed confusion about whether the corpse's clothes made any difference in temperature, how the corpse's temperature was taken, etc. Another member quickly replied, "But you don't have to worry about all those details. The model takes care of all that...." That insight quickly spread to other groups and helped their members, too, make a substantial start at solving the problem.

The student-to-student interchange that occurred with this exercise represents the kind of thinking one hopes students learn to internalize for their own problem solving. That Newton's model simplifies the complexities of the situation is something that an experienced instructor might explain while presenting the solution as part of a lecture; but, it is something that his students might well miss while busy copying from the board all the symbolic and numerical manipulations of the solution. Having the insight uttered by one student and understood immediately by others as they concentrated upon solving the problem themselves was a fortuitous instance of catching problem solving in action.

Collaboration: The several class sessions held in the computer lab near the semester's start were especially productive instances of cooperative learning. Discussion within pairs was generally very lively, and it was evident that students were helping one another, on matters that ranged from navigating windows on the Macintosh to understanding subtleties of *Mathematica* and *Mathematica's* representation of motions of the plane. This experience is something I have often seen before with paired work at computers.

On the homework problem sets, students were explicitly permitted and even encouraged to work together—provided they acknowledged their collaboration. Whereas no organization into groups was imposed, the students did work together in a variety of modes—in pairs, small groups, and large groups.

For the collaborative component of the first exam, no group score was derived; rather, each student wrote his own new or revised solutions after the in-group consultations. This scoring strategy was used because the purposes of the collaborative component were: (1) to provide at the exam, to some degree, an opportunity for help from others similar to what was available for homework problems, and (2) to evaluate students' ability to learn from consultation, but not their ability to contribute toward a collaborative effort.

The typical format for the in-class problem-solving exercises was a printed problem, possibly accompanied by introductory text, which was distributed to the class. Students were instructed to read the problem and then to individually attempt to start solving it. After everybody had a chance to think and work alone for some five to ten minutes, students were asked to work in a group with one or two neighbors. At first during the semester, nearly all students required repeated prompting to work in these informal groups; later, entering group mode usually required only minimal prompting.

Outcomes

In my Fall, 1998 offering of *Math 245*, the various reforms in general, and the innovations that semester in particular, had outcomes ranging from productive to disappointing.

Computer technology: Nearly all students did learn to use *Mathematica* productively, as was evident from homework papers and office-hour interactions. For unknown reasons, some failed to exploit it sufficiently during the exams where it was available. On homework, most students did not hesitate to use *Mathematica* or to seek out situations where they could do so. In fact, for homework many students employed *Mathematica's* mathematical word-processing capabilities to create a product with a polished appearance, despite no requirement that they do so nor evidence that a better grade would result.

Students did not report much use of Wattenberg's website outside class on their own. Why that was so was not ascertained. In any case, what was available there often duplicated what was in the text.

Homework problems: As measured by average homework scores, performance on the ten weekly problem sets was good to excellent for nearly all students (see Table 1).

Students were allowed and encouraged to collaborate on homework problems, but all too often groups of students submitted identical, or nearly identical solutions. This meant that a student who could not solve a problem, or who did not have the time to work on it, copied the solution wholesale from a classmate. *Math 245* students' common practice of preparing homework solutions in the form of *Mathematica* notebooks evidently facilitated plagiarism. Unfortunately, no mechanism was in place—aside from the independent check by means of exams—to ensure that students collaborated responsibly and accounted for their own contributions.

Table 1: Mean homework scores ($n = 19$)

Letter	Range	Percent
A	85-100	36.8%
B	75-84	31.6%
C	60-74	21.0%
D	50-60	0.0%
F	0-49	10.5%

Exams: The scores on the first exam, including both the individual and collaborative components, were distributed as shown in Table 2.

Table 2: Scores on first mid-term exam, with collaborative component ($n = 20$)

Letter	Range	Percent
A	85-100	5%
B	75-84	15%
C	60-74	20%
D	50-60	15%
F	0-49	49%

In view of the results, it would not be surprising that students were not uniformly enthusiastic about the format. In fact, according to a mid-semester questionnaire, the students were about equally divided as to whether they favored such collaboration for their remaining exams. Informally, individual students said that they preferred to have the entire time to work by themselves. Consequently, the collaborative part was abandoned for the subsequent two exams, although now the use of *Mathematica* was allowed. The results, shown in Table 3, were better.

Table 3: Mean of second mid-term and final exam scores ($n = 18$)

Letter	Range	Percent
A	85-100	22.2%
B	75-84	27.8%
C	60-74	33.3%
D	50-60	5.5%
F	0-49	11.1%

In-Class Problem-Solving Exercises: Overall, the in-class exercises were productive and well-received. Most students worked energetically on them, and many students informally told me they liked doing them. The in-class Exercise 5 concerning rigid motions of the plane and Exercise 6 about modeling a cooling corpse with Newton's law were especially efficacious. However, taking time for all the in-class exercises interfered with adequately covering in class all topics on the syllabus, and vice versa.

Overall course results: Among the students who enrolled in *Math 245* in Fall, 1998, many dropped the course during the two-week no-penalty add-drop period. Of those who remained, only 50% completed the course successfully, that is, with a grade of D or higher, and 42% officially withdrew after the add-drop period. On the whole, this situation—and *the results on the* first mid-semester exam that in part gave rise to it—was demoralizing to the students and disheartening to me.

Overall course scores were computed with weights of 54% for the average of all three exam scores, 36% for the best 8 of 11 problem set scores, and 10% for class participation. The distribution of course scores and corresponding grades is shown in Table 4. Whereas fully 40% of students still enrolled at the semester's end did earn grades of B or higher, that number represents only 22.2% of the students who remained after the add-drop period and a smaller percentage yet of all who originally enrolled.

Table 4. Course scores (n = 20)

Letter	Range	Percent
A	85-100	20%
B	75-84	20%
C	60-74	40%
D	50-60	10%
F	0-49	10%

Several *Math 245* students did truly outstanding work—and they became teaching assistants in the course the next year. One expects a few students in a typical math class to stand out above the rest; what is notable in the case of *Math 245* is that these few did so while enjoying a significantly richer and more challenging experience than they would otherwise have had in traditional courses.

Explanation of the Outcomes

There is no evidence that the disappointing results in the Fall, 1998, version of *Math 245* can be attributed to the specific innovations introduced that semester. Rather, in view of the actual situation and what students individually said to me about it, the following factors are plausible explanations:

1. *Math 245* included far too much material, especially difficult abstract material, covered at far too fast a pace. By treating all three subjects together and thereby avoiding repetition of topics common to them, *Math 245 & 246* together were designed to cover the material more efficiently. But in Fall, 1998, at the behest of a new, major client department for the course, the year-long syllabus was rearranged so as to cover in the first semester most of the linear algebra and all the ordinary differential equations content.

2. In *Math 245*, students experienced dissonance with their view of what a math course should be. They typically had done quite well in freshman calculus and may have had a fairly easy time

there, especially since so many had already taken calculus in high school. They were overtly hostile to being required to write prose explaining what they were doing, and they were unaccustomed to working problems with the aim of discovering a principle rather than, as in calculus, demonstrating they understood a method already taught to them.
In this regard, many students had a discouraging experience with their first problem set papers. Interpreting my grading directions too strictly, the graduate assistant who read homework papers was a stickler for complete, coherent write-ups; he gave little or no credit for correct answers that included minimally necessary calculations, but lacked adequate prose explanations.

3. Some students enrolled in *Math 245* because, they said, they thought that use of computing would make learning mathematics easier for them. They may have been under the illusion that because *Math 245* involved computing, less mathematical thought would be required than in the traditional courses.

4. *Math 245* students' initial hands-on experience with *Mathematica* at the class lab sessions was discouraging. When multiple users simultaneously accessed the same *Mathematica* notebook from the lab server, performance of the client-based *Mathematica* systems slowed to a crawl; saving files to a PC-formatted diskette—which in theory was possible with the Macintosh computers—caused erratic system freezes and, consequently, lost work. (A work-around and, later, a fix, were eventually found.) These frustrations persuaded some students to drop the course.

Concluding Remarks

The overall disappointing results in my Fall, 1998, offering of *Math 245* can be attributed in part to a changed client department profile. Previously, the *Math 245–246* sequence was merely one option available to all students who would take some sophomore mathematics. For 1998–99, the Electrical and Computer Engineering (ECE) Department—which had previously enrolled few students in the course—asked the Mathematics and Statistics Department to revise *Math 245–246* to better serve their own students. The plan was that all ECE majors would take the first semester, but only the electrical engineers would take the second semester. Because my department wanted to prop up enrollment in what had been a dangerously low-enrollment course, I accordingly revised *Math 245–246*. Most of the more difficult material from linear algebra and everything about ordinary differential equations would now be covered in *Math 245*, and the less abstract topics of surfaces and multivariable integration would be shifted to *Math 246*. This accommodation was made beginning in Fall, 1998.

For Fall, 1998, ECE strongly advised its majors to take *Math 245*, and many did enroll. But as soon as they faced a rapid pace, demanding workload, difficult and harshly-graded homework assignments, and a discouraging initial experience at the lab, a disproportionately large number of ECE students bailed out.

Evaluating the reforms and innovations in the Fall, 1998, version of *Math 245* ought to include comparing the experience there with what happened in preceding and succeeding years. Unfortunately, such comparisons are problematic. Prior to Fall, 1998, enrollment was smaller by roughly a factor of five, and the material was more reasonably distributed in amount and difficulty between the two semesters of the year-long course. Afterwards, in Fall, 1999, ECE majors no longer had the option to defect early. That semester, three lecture sections were offered, of which I taught only one. The other two instructors conducted their classes in a traditional lecture format. While the task of preparing homework problem sets rotated among the three instructors, the syllabus became more rigid and uniform across all three sections.

A premise of *Math 245–246* has been that students would be more motivated to learn, and better able to understand, the mathematical ideas if they realized how these ideas arise from solving problems about real-world situations. In point of fact, some of the "real-world" problems were more fanciful than real. And perhaps those, as well as some of the genuinely real problems, were simply not compelling for the clientele in this course—not things the students *really* wanted to know. Indeed, finding realistic problems in mathematics—especially ones that do not require unduly extended excursions into the field of applicability—is challenging, at least compared with finding such problems in a physical or biological science whose very subject is the real world.

In-class problem-solving exercises are a strategy that I not only would use in other courses, but have—predicated on the condition that the syllabus be more modest in coverage than is typically the case for such courses. Using such exercises in separate calculus, linear algebra, and differential equations courses has been successful, as suggested by positive student reactions and apparently positive effects upon student learning.

To get students to collaborate willingly on in-class exercises, and not just work individually, took repeated reminders and encouragement. By contrast, when students were paired in front of computers at the start-of-semester lab sessions, they immediately and freely communicated with each other and helped each other learn. For a few in-class exercises, students were allowed and encouraged to use the two computers available in the room; given the size of the class and the classroom layout—with the computers deployed in a front corner of the room—that arrangement was awkward. These considerations suggest that an ideal way to teach a mathematics course exploiting computer technology would be in a "workshop-classroom" where students work in small groups each near its own computer, but where the entire class can readily assemble for student or instructor presentations to the entire class.

This tale of *Math 245* is cautionary. My experience there indicates that active-learning strategies can be quite useful, but that they are unlikely to fulfill their promise unless the instructor is realistic as to how much can be covered. In the end, less may be more! ■

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Frank Wattenberg conceived and originally implemented the integrated sophomore course described here. To him I am indebted not only for demonstrating the possibility of application-motivated mathematics instruction, but also for specific guidance in using his written and electronic materials. Kenneth Levasseur suggested the adage "Less is more." Howard A. Peelle generously gave an earlier draft of this paper a critical reading; STEMTEC reviewers James A. McDonald and Richard Yuretich made useful suggestions for improvement.

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Bio

Since 1965, Murray Eisenberg has taught at the University of Massachusetts Amherst, where he is Professor of Mathematics and Statistics. His Ph.D. is from Wesleyan University. His main mathematical interest is the topology of dynamical systems. In recent years, he has studied cognitive and pedagogical issues of using computer programming to teach mathematics. He has published articles on topological dynamics, topology, the APL and J programming languages, and the use of computing in teaching math; he is the author of three advanced undergraduate texts. For more than twenty years, he has directed his department's undergraduate computer lab and used computers to help students learn mathematics.

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TEACHING INNOVATIONS IN AN INTRODUCTORY PHYSICS COURSE FOR NON-SCIENCE MAJORS

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I have made several innovations to *Physics 114: Physics of Sound*, a course for Communication Disorders and General Education students at the University of Massachusetts. These changes include the use of a network of wireless communication devices called a Personal Response System, on-line tutorials and classnotes, a collaborative discussion section, exam corrections, microthemes, extra-credit papers, group extra-credit projects, and the use of student teaching assistants.

Introduction

Several innovations, including the use of a "Personal Response System" (PRS), and the use of student teaching assistants, were integrated into *Physics 114: Physics of Sound*, a course presented to non-science students, in recent years. Below I give details of these changes and some student reactions to them. The course satisfies a University of Massachusetts General Education requirement and is an introduction to acoustics, with special emphasis on the speech and hearing mechanisms. It is required of sophomore majors in Communication Disorders (ComDis), but open to students in all majors. About 15% of the students are majors in other departments.

The students in the course are non-science majors and often enter the course with considerable trepidation. Thus, the course is designed for individuals who are not strong in mathematics; it is based primarily on a pictorial and graphical approach, with some algebra, of course, that students are capable of handling. Interestingly, because of the makeup of the Communications Disorders Department, 90% of the students in the course are female. This high percentage of female students in a physics class in a coed university is very unusual. Enrollment varies from 60 to 90 per offering.

I developed *Physics 114* in 1974 because of my own interest in sound, and because my wife, who is a speech and language pathologist, suggested that Communication Disorders majors might find it useful. Soon after, the Communication Disorders department made the course required of all its majors as a prerequisite for their Speech and Hearing Science courses. That department may be unique among similar departments at universities with this major in having this requirement. The policy of our Physics Department is for an instructor to teach a course three or four times and then to move on to another course. In three separate assignment periods, I have taught the course eleven times in the 26 year span of its existence. I have taught the course four times since 1997.

Innovations were made in the course as a result of advice from other instructors, to follow my own ideas on what could be useful, and as a result of being a part of the Science, Technology, Engineering, and Mathematics Teacher Education Collaborative (STEMTEC) Program at the University of Massachusetts Amherst.

The course is designed to be student-active, that is, the main feature of class time is students working, generally in small groups, to discover for themselves the answers to provocative questions and problems presented during class. This process is facilitated by a Personal Response System (PRS), a classroom communication device that allows students to send answers to a central computer where they can be recorded and summarized for the class. Some lecturing is done, but students are expected to have read the material to be treated in any particular class before that class. A set of classnotes [1] and a website are provided for that purpose. An important feature of the class is the illustration of important points by means of physical demonstrations; in a course on sound it is important to hear what you are talking about. However, this feature is not an innovation in a physics course and will not be discussed further here.

Among the more notable features to be discussed below are PRS, an on-line tutorial, the use of undergraduate student teaching assistants, and group projects. The main goal of these and the other activities discussed is to provide many pathways for students to learn with an emphasis on a constructivist teaching philosophy, in which the instructor is only a facilitator of the learning carried on by the student herself.

Techniques Used

Some of the innovations used are described in this section.

Personal Response System:

The Personal Response System, developed by Better Education, Inc., of Yorktown, Virginia, is a wireless communication device that we installed to replace the wired networked system *Classtalk* (also developed by Better Education, Inc.) which had been used by my most recent immediate predecessor in the course, Prof. José Mestre [2]. Both systems allow student communication with a central computer that compiles and displays student answers to in-class questions. While *Classtalk* is an excellent system, I find PRS is much simpler to use and has a less steep learning curve for the students. Our *Classtalk* system had been breaking down regularly due to old age. *Classtalk* is much more flexible, allowing various answering procedures, and gives the instructor more comprehensive information; PRS allows only answers 1-9. Nevertheless, I found that was sufficient and preferable for my purposes.

With PRS, each student uses a small handheld infrared transmitter much like a TV remote control. A receiver, mounted on the front wall of the classroom to detect the student responses, is connected to a central computer that contains proprietary software to tabulate and record the incoming data. The final results are projected as a histogram on a screen in the front of the class. Data is recorded in a text file that is easily transferred to a spreadsheet program. While it might be possible to have students purchase the transmitters (approximately $50 each), the Physics Department purchased a large set of these for use in several classes. At the beginning of each semester, each student was assigned a particular transmitter number, and at each class the student checks out that particular device. An answer transmitted from a device is identified as coming from that particular device. Thus, for example, attendance can be taken with the system and quizzes can be given. By placing groups of three transmitters in plastic bags, one student could pick up the devices for herself and two classmates from a rack near the door. Even with seventy students there was no class delay in setting up.

With either system, students work actively on questions or problems, discuss these in small groups, present individual answers, discuss as a class, and see how they did via a projected histogram. The main advantage is student participation, but seeing how they are doing relative to the rest of the class is no small benefit. The instructor has immediate access to student feedback as well, and can tailor his or her presentation to how well the students are doing on particular tasks. I also use PRS to take attendance, which earns credit on the final grade. Here is a typical in-class question:

The use of the term "sound wave" in air is meant to describe:

1) the position of air molecules
2) the velocity of air molecules
3) pressure variations in air
4) the flow of energy through air

The entire set of questions can be seen on-line at the course website discussed in the next section. As one can see, not all questions are mathematically couched. They tend to be qualitative, and sometimes even ambiguous, so that student discussion is provoked. Most of the questions I have used were developed for *Classtalk* use by Prof. José Mestre for the student-active approach he has used for many years [2,3]. Once the students have keyed in their answers, I ask for a student to explain her answer to the class. In the ideal case, there is disagreement among the students so that a lively discussion ensues. However, I have always found it difficult to get students who are unsure of their answers to volunteer to take part in the discussion. Thus, a student orally responding to the question is usually one who really knows the right answer and debate is sometimes limited. Nevertheless, students are very appreciative of the approach, because they are getting a chance to test their understanding with the material presented in this way at a pace that allows them to keep up.

A crucial aspect of such an approach is the decrease of lecture time available to present material in a standard manner. The students are encouraged to read the classnotes before class time. Some actually do this! It is not a great burden since, on average, we cover only five pages of notes per class period. Short lecture and demonstration periods are interspersed with the questions in the class period.

<u>On-Line Tutorial and Classnotes:</u>

The course has a website at <u>http://www-unix.oit.umass.edu/~phys114/</u>. On the site are classnotes [1] written by colleagues and me. While the students have a printed copy of the classnotes, made available through the University bookstore, the on-line version contains animations of waves, etc. that are impossible to reproduce adequately in the printed version. The other useful feature is a tutorial containing all the PRS questions used in class. A student not following the class discussion, missing class, studying for an exam, etc., can actively work on a question on-line. She chooses a multiple-choice answer, is told whether it is correct or not, is offered a reference to the classnotes and a helpful hint, and then, if necessary, is given a detailed correct answer. In the latest offering of the course, students were also able to obtain a CD-Rom disk containing the website if they liked. Despite giving out many of these, the on-line site received about 300 hits during the semester.

<u>Collaborative Discussion Section:</u>

An afternoon discussion section is required to fit into the students' schedules. This feature was instituted some years ago by Prof. Mestre to help replace some of the help sessions necessary in this course. From the very beginning 26 years ago, it was evident that the lectures I was presenting were not enough for the all the students to master the homework and other material of the course. Thus, I instituted help sessions at various times during the week. Offering a scheduled discussion session is a much better way to fit in such a session. It is optional and about half the class attends. I use it in a group collaborative approach, where groups of students help each other on the weekly homework, while the course TA's and I go from group to group offering advice. This procedure is much preferable to one in which an instructor is standing at the board doing the problems for the students as is often typical in discussion sessions in other courses.

Microthemes:

Because of the large class size (71 in Spring 2000) computer graded homework and exams are very timesaving. However, I prefer at least some essay questions on exams. Thus, the hour exams usually each have one microtheme question included. A microtheme [4,5] is an essay that has a short length requirement. In my case I present a box, 7.5in x 3in, into which the answer must fit. The question is always qualitative and an accurate answer requires the student to understand the meaning behind the math, rather than having, for example, memorized a formula. An innovation is that I give out three possible questions during the week before the exam, so the students can prepare answers *ahead of time*. (This forewarning unfortunately does not result in 100% correct answers; indeed, in Exam 1 in Spring 2000, only 25% of the class got full credit for the essay, while, in Exam 2, that number improved to 63%.) The questions are easy to grade; one spends perhaps 2-3 minutes per student. The major advantages of the questions are that they force the students to think deeply about the three selected topics before the exam, and they are an excellent diagnostic tool for determining qualitative understanding. A typical question is,
"Why does a standing wave 'stand' rather than 'travel'?" This question requires that the student understand the distinction between standing and traveling waves, and understand the role of reflection at boundaries and interference in the establishment of standing waves. It is easy to tell from the answer in the box whether the student has mastered each of these rather complex ideas in at least a qualitative way.

Exam Corrections:

The idea of a "pyramid" exam or its variation, as a help to learning, is very popular among STEMTEC participants. Locally, this process is often formulated so that after finishing and handing in an individual answer sheet, students rework the exam in small groups, getting 10% or more of their grade for the group answers. I prefer a variant of this. After an hour exam, I announce that students may gain 5% of their test grade (sometimes less) by writing a couple of sentences for each wrong answer, explaining why it was wrong, and what the correct answer is and *why*. They have a week to produce these corrections and are allowed to consult any source. This optional assignment can result in as much as three pages of corrections, which are time-consuming to assess, but invaluable in getting students to think about their mistakes. It also puts a premium on understanding not only what the answer is, but why. Students report this exercise is extremely useful. I explained the usual pyramid exam procedure to my TA's (former students in the course) and asked them whether they thought they would have preferred that or my approach. They were unanimous in favoring my approach.

Extra Credit Options:

Since the Communication Disorders students are very interested in performing well in this required course (most need to get into graduate school to obtain a master's degree for certification) earning extra credit is a popular recourse. There are two main modes of receiving extra-credit points: essays and projects. At two points in the semester, a student may gain extra credit by writing a five-page paper. I like the idea because most of the assignments in the course are multiple-choice and this gives the students a chance to show their extended writing abilities. Topics for writing have varied widely; examples are earthquakes, the physics of singing, echolocation in bats, etc. The two papers, if they gained full credit, could raise a student's grade by 6%, or one letter level.

In accordance with suggestions from writing specialists, papers go through a drafting process. A first draft is handed in; I distribute it to another student writer, who prepares a detailed evaluation of the paper using a form I designed. The paper is then re-written on the basis of the suggestions from the peer review. In an ideal world, I would read the draft as well and give the writer feedback, but I have not done this every time. I see the first draft and the peer review when I read the final draft. The entire process is done in plenty of time before the end of the semester so that the student is certain to see my comments on her writing (unlike many "term" papers that never actually get picked up by the student).

A second extra-credit possibility is a group project. Groups of students, preferably four, but occasionally two, three, or five, decide on a project that they can present as a 15-minute oral demonstration on some class-related subject. The subjects vary from a spectral analysis of a musical instrument to the physics of the middle ear. I observe the demonstration and give a group grade. Each student is then required to summarize the project in an independently written, four to five page paper, which results in an overall project grade for that student. The maximum extra credit is an 8% grade change. In principle, the best demonstrations would be presented to the whole class if there were time, but I have not been able to fit it in. Students review drafts of each other's papers, which helps improve the final product, before I read them.

An advantage of this process is that students are working together and are teaching each other. The papers are less stilted and less formal than those described above because the projects go beyond the usual textbook formulation and involve some original thinking. The students find these projects fun to do and often become very enthusiastic about the ideas they develop. The oral presentations that they must make help develop yet another useful skill.

Topics here can be quite unusual. One group in 1999 decided that they wanted to break a wine glass with sound waves as seen in a popular television ad for recording tape. This is not easy and requires a special speaker, which I did not realize at the time. But what the students came up with was interesting: they could not break the glass (actually a beaker), but they could see its resonance by noticing the motion of sand sprinkled on a card placed on top of the beaker. The approach wasn't as dramatic as breaking the beaker, but it was probably more educational. (In Spring 2000, I found the department had the required speaker and amplifier and I incorporated the breaking beaker as a *pièce de résistance* classroom demonstration.)

The extra-credit paper avenue has not been as popular in recent times (in Spring 2000, only three students used this option) as the group project. This spring, 36 students involved in ten groups participated in the latter approach to extra credit. Part of the reason is perhaps that the project is worth more credit, but I decided that the group work was a more valuable experience and raised the possible point total to encourage its use.

<u>Student Teaching Assistants:</u>

Having student teaching assistants is probably the single most useful innovation in the course. I ask three of the top students from the previous year's class to act as TA's in the current semester. The TA's are "paid" with independent study course credits, up to three, depending on how much time they are willing to spend. Amazingly, the students I ask have always agreed, and this semester I had two wonderful students return for a second year's work. Often good students come in to *volunteer* to become TA's in the course. The TA's do not do any grub work such as grading homework, doing errands, helping with proctoring, etc; they only tutor, hold office hours, and teach help sessions. This feature provides many extra hours a week of help for students in the course, who seem more willing to look to their peers for help than to come "bothering" me, even though I do encourage them to come to me for help. One of the goals of the STEMTEC grant was to encourage students to enter science teaching. It is possible that this student teaching experience may encourage former Communication Disorders TA's to go into school special education rather than into the more lucrative hospital work. While special education is not explicitly science teaching, it can affect the quality of the latter rather directly. The independent study grade is based on my assessment of how well the TA performs in that role, including mundane things like adequate preparation for duties and not missing office hours, and more importantly how well she interacts with the students as I observe in the discussion section. In some cases, I have in addition required a paper on some aspect of sound beyond that covered in the course.

Conclusion

I have made no formal effort to determine whether the students learn more or retain the information longer with the use of these innovations. I do know that my student evaluations have risen greatly over the last few years, as evidence that the students very much appreciate the way I now teach. My experience is that happy students are much more likely to learn, so I recommend these approaches. ■

Acknowledgments

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EXPERIENCES AND THOUGHTS ON STEMTEC-INSPIRED CHANGES IN TEACHING PHYSICS FOR LIFE SCIENCE MAJORS

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I have taught an introductory course for life science majors three times, each time introducing one or more teaching techniques discussed during the Science, Technology, Engineering, and Mathematics Teaching Education Collaborative (STEMTEC) meetings. Typical class size was 275 students. I cannot make quantitative statements about comparisons between the results of STEMTEC-type teaching methods and *traditional* teaching methods because I have never taught this course in a completely traditional lecture style. During the first year, I introduced conceptual questions into my lectures. The lecture would be interrupted several times with questions posed to the class. The students then had several minutes to discuss each question among their neighbors, then present their answers. During the second year, I switched from traditional homework to a computerized system which allowed instant feedback to the students, and the ability to resubmit solutions to problems they had not successfully solved. I also introduced an exam format that enabled the students to work individually, then redo the exam in groups and hand in a second set of solutions. The goal of each of these techniques was to increase the engagement of the students with the material of the course. Each of the techniques had both successes and limitations. The most serious problems I confronted were technical difficulties which diverted attention from the tasks at hand to the necessity of *keeping the system functioning*.

Introduction

Physics 131: Introduction to Physics I at the University of Massachusetts Amherst (UMass) is an introductory course designed for life science majors, exercise science majors, pre-medical students, and others who need a non-calculus based introductory physics course. There is an emphasis on applications which are important in the life sciences. The topics covered are mechanics, fluids, waves and acoustics, with a small amount of heat and thermodynamics.

Because it is a required course for a number of majors, the beginning enrollment in the fall semester is typically more than enough to fill the 290 seat lecture room in which it is given. The Department of Physics at UMass typically assigns a faculty member to teach a course no more than three or four times in a row. Thus, no faculty member *owns* a given course, and every faculty member teaches lower level undergraduate courses, as well as upper division undergraduate and graduate courses.

I was assigned to teach *Physics 131* for the first time in the fall of 1997, and I taught it

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during the two succeeding fall semesters as well. Each time I taught the course, I introduced one or more STEMTEC-type, student-active teaching methods, described below. Because I have never taught this course in a completely *traditional* lecture-only format, I cannot make quantitative comparisons of the results of *traditional* and *student-active* teaching methods of the material. However, I feel that I have enough experience with the course to point out both the advantages and disadvantages of these newer teaching methods.

The Goals in Using STEMTEC Techniques

The main goal of STEMTEC-inspired techniques I used is to increase student-active learning. More specifically, I wanted to:

- induce students to **think** about the physics under discussion **during class**
- induce students to **interact with each other** as a learning experience
- give students **immediate feedback** on the status of their activities, both their in-class student-active learning and their after-class homework assignments.

The Techniques Used

I attempted the first goal, getting students to think about the physics during the class meetings, by presenting them with conceptual questions during the lecture [1]. (Sample question may be found in the section, "A Conceptual Example.") The students were given several minutes to discuss each question with their nearest neighbors, then register their answers. The results were shown to the entire class. The first two times I taught the course, the students held up numbered sheets with their answers. In 1999, I switched to using the *Classtalk* electronic polling system described below [2,3,4]. Both methods enabled me to immediately see how the class was doing, and immediately address misconceptions that arose. The *Classtalk* system, however, made it easy to have a record of each student's activity.

In addition to interacting with each other during class, students were also encouraged to work together during exams, which were modified pyramid exams [5]. The students first worked independently on the problems and handed in their solutions. Then they worked on the same exam in self-selected groups and handed in another set of individual solutions. When it worked well, this interaction encouraged students to engage each other, forcing them to defend their viewpoints when conflict arose and increased their understanding of the material, their ability to manipulate the material, and the concepts to solve problems they had not previously encountered. The grading system for these exams is discussed below.

In the fall of 1998, I switched from the traditional homework system, with problems handed in once a week and graded by a graduate teaching assistant, to the On-line, Web-based Learning (OWL) system [6,7]. This system notifies the students immediately of their success in solving the problem at hand. If they do not succeed, the system gives them the correct answer and also the option of getting some *hints* and then trying the basic problem once more with a different set of numbers. Thus, the students can work the problems until they have solved them all.

Grading in the Course

The *Classtalk* conceptual problems counted for 10% of each student's grade. The OWL administered homework counted for another 20%. There were three evening "midterm" exams, worth a total of 50% of each student's grade: the exam on which the student got the lowest score counted for 10% and each of the others counted for 20%. There was also a final exam which counted for the remaining 20% of the student's grade.

Conceptual Problems and the *Classtalk* System

The purpose of the conceptual problems is to counter the idea that many students have that physics consists of inserting numbers into formulas for the sole purpose of getting a numerical result. The problems are designed to probe the basic understanding that the students have of the material. To the extent that numbers come into the picture, they usually come in as ratios. A good source of conceptual problems is reference [1]. In addition, many of the newer physics textbooks include conceptual problems either as separate sections, or along with the regular end-of-chapter exercises.

The *Classtalk* system consists of hard-wired connections between student calculators and a computer operated by a teaching assistant. Up to four students can sign onto a single calculator, each with their own unique ID. The students can enter the answer to a given question as individual answers, or as a group consensus answer with the possibility of dissenting answers from one or more members of the group.

When a question is posed to the class, the students are typically given three minutes to register their answers. In order to encourage both attendance and thought about the problems, one point of credit is assigned for an answer to each question, with an additional ½ point for the correct answer. At the end of the allotted time period, a histogram, generated by the computer, is displayed on the projection screen. This histogram tallies the answers to multiple choice questions, or numerical intervals to questions where a numerical answer was requested. The class and I immediately see what the response was to the question. If more than 90% of the answers are correct, I briefly comment on the problem. If more than about 10% of the students do not get the correct answer, I spend much more time going over the problem, stressing the concepts necessary to deal with it, and pointing out typical misconceptions that can arise. On average, a single problem takes a total of about ten minutes of class time. I consider a student getting 85% of the maximum number of points during the semester as having done enough to get full credit for the *Classtalk* part of their grade.

A Conceptual Example

To illustrate the type of conceptual problem used in the class, a problem involving motion in the vertical direction under the influence of gravity is outlined below. The students will already have understood the concepts of velocity, acceleration, and maybe the invariance of physical laws under the operation of time reversal.

> *A ball is dropped from the top of a building. It strikes the ground with a velocity v_f. At the instant the ball is released, a second ball is thrown upward with an* ***initial velocity*** *v_f. Ignoring air resistance, where will the paths of the two balls cross?*
>
> *(a) At the half-height of the building.*
> *(b) Below the half-height of the building.*
> *(c) Above the half-height of the building.*

There are several ways to approach solving this problem. One way involves asking (and answering) the following questions:

1. Will the thrown ball reach the top of the building and not go any higher?
2. Do the two balls take the same time to get from the top (bottom) of the building to the bottom (top)?
3. Will the balls pass each other half way in *distance* or in *time*?
4. If the time for the dropped ball to reach the ground is T, how far will it drop in T/2? (Note: The distance, d, the dropped ball falls in a time t is given by alignl d ~=~ 1 over 2 `gt^2, where g is the acceleration of gravity.)

This problem seems simple when asked, and the calculations involved are simple, but unless the students ask themselves the correct questions while solving it, they will be led astray.

For the curious, here is the solution to the problem:

1. The thrown ball will just make it to the top of the building.
2. The dropped ball takes the same time to reach the ground that the thrown ball takes to reach the top. Points 1. and 2. are intimately involved with the time reversal invariance of physical laws.
3. Because of 1. and 2., the balls will pass when *half the travel time* has elapsed, not half the travel distance.
4. If it takes the dropped ball a time T to reach the ground, in T/2 it goes 1/4 of the distance (because of the dependence of the distance traveled on T^2 rather than *T*). This means that the balls will cross paths above the half-height of the building (1/4 of the way down from the top of the building).

Homework and the OWL System

The ideal distribution of homework is to have problems based on material covered in a class due before the next class meeting. This way, the students are forced to think about the material as it is presented and not put off doing the homework for an extended period of time. In addition, I hear about questions on the homework at the beginning of the next class period and can address them immediately.

Under the *traditional* homework system, homework is due once a week, graded by a graduate teaching assistant and returned the following week during a discussion session. That system has several drawbacks:

- Many days pass between the material being covered in class and when the homework is due
- There is not much chance for help while a student is experiencing difficulty with a problem
- By the time the graded homework is returned, the student has forgotten what the problem was, how they tried to answer the problem, and what difficulties they encountered

The OWL system is an attempt to address these problems. I assign more problems than I did when all I had was a graduate teaching assistant to grade the problems (the computer doesn't get worn out grading homework of 300 students). Instead of being due once a week, the homework based on a class meeting is *due before the next class meeting*. This way, the students are continually doing work in the course. Typically, three homework problems are assigned after each class meeting.

To do their homework on the OWL system, the students sign on to a secure website (only registered students have access to the site). They can choose which problems to attempt and in which order. Each time a problem is presented, the numbers in the problem will change (but always consistent with the laws of physics). As soon as a student has entered an answer to a problem, they are told whether or not they have answered it correctly. If they did not answer the problem correctly, they are given the correct answer and the option of getting a hint on solving the problem. These hints usually consist of an indication of which physical principle(s) are applicable in solving the problem. The student is then given the option of trying to solve the problem again. Of course, the next time they see the problem, it is the same problem, but with different numbers. They may also elect not to try the problem again at that time and come back to it later, or in a different session. This process can be repeated as many times as the student wishes before the problems are due.

The advantages for students of the OWL system are instant feedback, some help if needed, and the ability to attempt the problem as many times as necessary until correctly solving it. The Physics Department maintains a Resource Room staffed by faculty and graduate students, open from 9AM to about 8PM, where the students can do their OWL homework (there are a number of computer terminals in the room) and get help on the spot if they need it from a living, breathing, person. Because the homework is web-based, the students also have the option of doing their homework in their rooms at any time of the day or night, as long as they have access to the World Wide Web.

During the course of the semester, more than 110 OWL problems are assigned. Students get full OWL credit for correctly solving eighty of these problems. This is done to lessen the burden on me of having students in my office every time they could not do an assignment because they did not have the time, or were sick, or had to attend a funeral, or were out of town, or . . .

The Pyramid Exam Technique

Evening midterm exams were multiple choice, two hours in duration. Each student worked on the exam individually for 1-1/4 hours, then turned in their answers. If they finished early, students were allowed to leave the room and discuss the exam with other students who had finished. At the end of this *individual* exam-taking period, the students formed groups of 3-5 (the group members were determined by the students themselves) and reworked the same exam for the remaining 45 minutes. Each student turned in an additional set of individual answers after the group effort. Thus, students got the benefit of interacting with each other on the material, but were not bound by any group decisions. In the best groups, the students vigorously discussed and argued about solutions to the problems over which they disagreed. In the unsuccessful groups, the students just copied the answers from a student who they considered better at the physics than they were.

The responses from the *individual work* were worth 80%, and the responses from the *group work* were worth 20% of the total exam grade. Thus, one correct answer on the *individual exam* was worth four correct answers on the *group exam.* The grades of students were raised by the group work, but not by much. However, the students learned from the group work, and at the end of the experience they understood the material much better. This was true even of the better students, who gained from giving explanations to the weaker students.

It was not possible to use the pyramid exam concept for the final exam because students from other courses were taking final exams in the same space at the same time as the students from my course; the noise from the group work would have been too disruptive to the students in the other courses.

The "Good Stuff"

I see a number of benefits from using the techniques described above:

- Attendance in class is much better. About 75% of the students are attending class even near the end of the semester. This is significantly more than the usual ~50% for large classes.

- Students are actively involved during lecture in thinking about the physics and interacting with each other.

- Students are learning from each other during class (*Classtalk*) and during the (pyramid) exams, and enhancing their knowledge of the physics.

- Homework is due in proximity to the class coverage of the material. Students can work on the homework problems until they understand them. They get instant feedback on how they are doing.

- Student interaction with the instructor (me) is greatly enhanced.

The "Bad Stuff"

There are, however, also some endemic problems:

- Attendance in class is much better. Students who really don't want to be there feel that they must attend class or they will lose credit on the *Classtalk* part of their grade. Uninterested students can be disruptive; they also are present during evaluation of the faculty at the end of the semester, with the obvious result.

- There is a problem of phantom students being signed into the *Classtalk* system by their buddies. This is easily dealt with, because the *Classtalk* system attaches the names of the students signed in to the seats they supposedly occupy. The teaching assistant then uses a seating diagram on the computer to find seats not occupied, but which have students signed in on them. An announcement to the class that we know who was signed in but not present, and also who signed them in (because we know onto which calculator they were signed in), and that both parties would lose credit for a week's worth of *Classtalk*, usually ends the problem.

- Not all students in groups during either *Classtalk* problems or during the pyramid exams are really interacting with their neighbors.

- With a class of 300, there are always a number of students who cannot take exams during the assigned exam time because of conflicts with other exams, work, etc. These students take makeup exams, but the timing of these makeup exams does not always allow each student to join a group.
  There are also a number of students, usually about half a dozen, who take untimed exams. Some of these students have documented learning disabilities and require extra time; others come to me after the first exam requesting extra time for subsequent exams. I usually arrange for these students to take their

individual exams earlier during the day of the scheduled exam and then show up at the main exam in time to take the group part of the exam. This is done in a way that minimizes the possibility of these students getting copies of the exam to others before the main exam is taken by the majority of students.

- Some students spend lots of time trying to "reverse engineer" the OWL homework. They will get a problem wrong and be given the correct answer (e.g., they may have said the answer was 5.2, and the correct answer is 10.4). Then they try the problem again, with different numbers, of course, and get it wrong again (e.g., they think the answer is 4.1, but the correct answer is given to them as 8.2). They will finally try the problem yet another time, but enter an answer that is different than the one they have calculated (e.g., if they think the answer is 3.7, they will not give the answer as 3.7, but as 7.4, assuming that the correct answer is really twice what they calculate). These students are not learning much physics when they do this, but it does happen (one group of students actually complained to me that many of the problems were taking too much time to reverse engineer—my response was that the point was to learn the physics, not just get the correct answer).

- Even though I allow the students ~30 "freebies" on the OWL homework, a number of students still pester me continually to extend the deadlines for the homework so they don't lose any possible credit.

- Some students just stop doing the homework after getting eighty correct problems.

Startup and System Problems

There were a number of what can be classified as startup problems:

- OWL — Students who register late for the class and hence cannot get onto the OWL system quickly are frustrated. In addition, if the main computer goes down, the students cannot complete assignments until the computer is back on-line. More frustration. This is a real problem if the computer goes down at 2AM (the homework is due at 4AM), while the student is trying to finish the assignment, and there is no way the computer will be brought back up until after 8AM.

- *Classtalk* — There is a logistical problem getting students signed onto the system in the beginning of the semester. Also, because the system is hard-wired to each seat in the lecture hall, sometimes the connections fail and the students cannot communicate with the main computer. This leads to more frustration and disruption of the class if not handled promptly.

- Pyramid exams — There are sometimes students who do not wish to share their knowledge with other students and refuse to join groups. As one student said to me: "I studied very hard for this exam. Why should I help someone else who has not put as much effort into preparation?" I try to convince such students that they will also learn as they teach someone else. If they still persist in refusing to join a group, I let them be a group of one for the second part of the exam. Usually, by the next exam, they have changed their minds about joining a group.

General Observations and Conclusions

- Students are *obsessed with credit.* This is especially true of students who feel they need good grades to gain entrance to competitive professional schools after college.

- Anything that prevents students from getting credit upsets them greatly. So, if the mechanics of the techniques being used are not in perfect working order (OWL downtime, *Classtalk* connection problems), the students are worrying about not being able to get credit instead of thinking about the physics.

- Most students really like the increased interaction with other students and the instructor fostered by the active learning paradigms.

- Students may actually learn and retain more compared to being taught in the traditional lecture style. I think the best way to check this would be by administering what I like to call the "Stop & Shop Test" to the students: You run into a student in Stop & Shop about a year after they have taken the course, and you administer an exam on the material to see how much they have retained. ■

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Bio

Monroe Rabin is Professor of Physics in the Department of Physics at the University of Massachusetts Amherst. In addition to an interest in improving teaching methodology, he does research in the areas of heavy-ion physics and medical physics.

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PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition

THE MATHEMATICS OF INFORMATION SCIENCE

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This paper describes a course, *The Mathematics of Information Science*, which was taught at Towson University in Spring 1998, 1999, and 2000. This course is the junior level interdisciplinary course of the Maryland Collaborative for Teacher Preparation program. The effectiveness of the course in teaching problem solving techniques and abstract mathematical ideas is documented. The students constructed their own knowledge from laboratory experiences involving digital logic circuits. They were subsequently challenged to abstract this knowledge and to find ways to solve progressively more difficult problems using these digital logic circuits. The mathematics of encoding and decoding information constituted the major mathematical content of the course. This course is shown to be effective in introducing prospective elementary and middle school teachers to abstract mathematical ideas and problem solving techniques.

Introduction and Description of the Course

The purpose of this paper is to describe a course called *The Mathematics of Information Science* and to document its effectiveness. *The Mathematics of Information Science* is a junior level interdisciplinary course in the Maryland Collaborative for Teacher Preparation (MCTP) program. The MCTP is a program for prospective elementary and middle school teachers who want to be better versed in mathematics and science than the average elementary or middle school teacher.

The educational objectives for this course are:

- To introduce the students to some high level mathematical ideas and notations
- To teach the students to generalize from an example to an abstract concept
- To help the students become more effective problem solvers
- To teach the students to break complex problems down into simpler pieces
- To help the students become more comfortable with technology

These objectives are consistent with recent national standards [1,2].

The central theme of this course is the representation of information using strings of bits. The course also focuses on correcting errors that can occur when information is encoded in this way. This material allows some high level mathematics and computer science to be taught using hands-on discovery based techniques. Although the content of the course is important since

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computers represent information in this way, the pedagogical approach is even more important since the students who take the course are prospective elementary and middle school teachers. Our teaching method is characterized by a hands-on constructivist approach to education as espoused by the MCTP [3]. This guided inquiry-based hands-on technique leads to a deeper understanding and retention of the course material. Before taking this course, MCTP students have to take three mathematics courses, two life science courses, and two physical science courses. Thus, the students were familiar with the MCTP approach.

The course began with a survey to assess the prior knowledge of mathematics, science, and computer science possessed by the students. Specifically, we asked them about their familiarity with various software packages, Internet experience, programming experience, and most of the mathematical topics covered in this course. All of the students had some familiarity with e-mail and the internet and usually some other software. None of them had any knowledge of computer programming. All of the students had the enhanced MCTP version of the two mathematics courses required for elementary education majors. The other mathematics courses most commonly taken were basic statistics, discrete mathematics, and calculus (many in high school). Finally, many students asserted that they remembered none of their previous mathematics.

Pedagogical Approach

Typically, we presented each topic in five phases:

1. Background Phase — We introduced the students to each topic and gave them any necessary background information.
2. Laboratory Phase — The students explored the topic in the laboratory phase using either pencil and paper or circuit boards. The students worked on the lab assignments in groups.
3. Summary Phase — We discussed the mathematical concepts underlying their laboratory work. This was often a discussion with students sharing what they discovered, but on occasion it would be a lecture. It must be emphasized that this lecture would always follow the laboratory work so that the students had concrete experiences on which to build.
4. Journal Writing Phase — The students were required to write about their experiences. This allowed the students to reflect on their new knowledge. We encouraged them to share their thoughts and feelings about what they were learning.
5. Journal Reaction Phase — Finally, we answered questions and cleared up any misconceptions that the students might have.

We found this five-phase approach to be extremely successful. In particular, it was encouraging to see the students make discoveries on their own.

Journals

The students were required to keep a journal and to write a journal entry for each class. Each journal entry was graded "acceptable" or "not acceptable." If a journal entry was not acceptable, the student was allowed to rewrite and resubmit it. This policy was instituted to discourage hastily written and poorly thought out journal entries. We found that the journals helped the students reflect on what they learned during the class period. Some students even anticipated in their journal what was coming next in the course. Our instructions for journal entries are given in Figure 1 below.

Figure 1

Journals for *Math/Cosc 326*

Your grade in *Math/Cosc 326* is determined in part by a journal that you keep. Your journal will record your thoughts and impressions about the course and about its content. You are to write in complete sentences with good grammar. We prefer that you type it although a neatly handwritten journal is acceptable. You should keep it in a ring binder and each written page is to be encased in clear plastic.

Each week in the Thursday class, you will turn in the entries that you have made for that week. You are required to have an entry for each class after the first week. You should also have entries about homework, projects, papers, etc. Your entry for each class should include, but not be limited to, the following information.

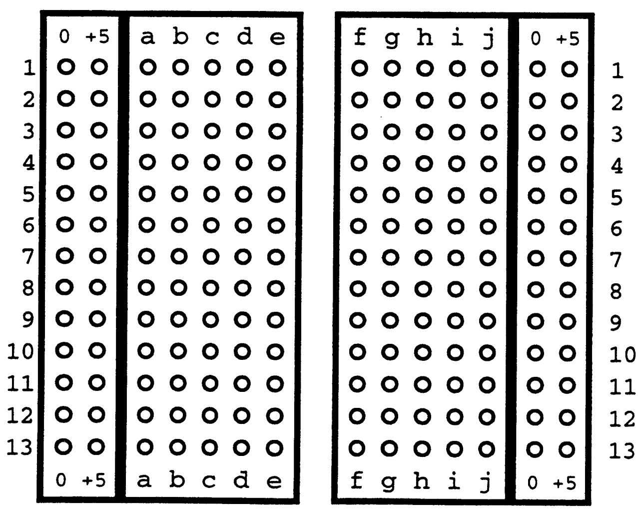
1. What did you do in class today?
2. Summarize what you learned from today's class. Be specific and give details about the content. Include diagrams, tables, formulas, etc. where appropriate.
3. Explain how this material is related to previous lessons. Speculate on what we will do next in class.
4. Comment about how you feel about this lesson.
5. Miscellaneous Comments.

In addition to the journals, the students were asked to write a small paper and to wire simple projects on the circuit boards (see Appendix A for a sample lab project). In 1998, we required the students to write a paper on the concept of a metric. In 1999 and 2000, the topic of the paper was equivalence relations. This change was instituted because a superficial Internet search on the word metric invariably came up with non-mathematical uses of the word metric, which confused the students. The course culminated with a final project. Each student group was required to design, build, and demonstrate a more complex circuit designed to do a specific task. See Appendix C for the list of suggested final projects given to the students. To test the students' knowledge of the content of the course, we gave a midterm and a final exam.

Overview of the Course

The course began with a discussion of bits as abstract entities and how they can be realized by 0 : 1, off : on, or open : closed. After some preliminaries, the breadboards were introduced and the students were shown how Light Emitting Diodes (LEDs) placed on the breadboards can represent bits (as off : on). The breadboards used to wire the laboratory experiments have the configuration given in Figure 2. Components can be inserted in a breadboard without any need to solder connections. These components can be purchased from an electronic supply catalog [4].

Figure 2



Each of the small circles in the diagram represents a connector into which components, such as resistors, LEDs, and integrated circuit (IC) chips, can be inserted. The pins are connected in the following way to allow convenient connection of the components:

- Power is supplied to the components by the columns labeled 0 and +5
- In each of the 13 rows, pins a, b, c, d, and e are connected and pins f, g, h, i, and j are Connected, but none of the pins a-e are connected to the pins f-j

Once the students developed a circuit design, they could proceed to use a breadboard to conveniently implement and test their design.

One of the main components of the course is learning how to wire circuits on the breadboards. We gradually guide the students into designing circuits to solve increasingly complex problems. They also learn that there are different ways of viewing a circuit. For example, they could describe a circuit by writing an algebraic expression for the circuit, developing a table that describes the function of the circuit, or realizing the circuit visually by giving a circuit diagram. Knowledge of these different ways of viewing circuits can enhance the student's understanding of circuits and the student's ability to design circuits to solve problems. See Figure 3 for an illustration of this.

Fig.3

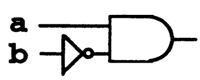
Algebraic Expression

$$a \wedge \sim b$$

Table

a	b	a ∧ ~b
0	0	0
0	1	0
1	0	1
1	1	0

Circuit Diagram



The mathematical topics of logic and Boolean algebra [5] are discovered (with some help from the instructors) in a very natural way. It is refreshing to have the students actually begging the instructors to teach them the techniques of the propositional calculus and Boolean algebra so that they can use these principles in their own circuit designs. Another component of the course, which overlaps circuit building, is the study of simple error correcting codes. This topic provides an opportunity to introduce various mathematical ideas, such as equivalence relations, base 2 arithmetic, isometries, logarithms, matrices, metrics, modular arithmetic, permutations and combinations, probability, and Venn Diagrams. Details are provided in the subsequent text showing how these topics are developed. To conclude the study of error correcting codes, bar codes are discussed and the students figure out what errors will and will not be detected in a bar code.

Specific Activities

We began the course with some simple activities designed to get the students thinking about representing information using bit strings. For example, we asked the students how many bits are needed to represent each of k objects by a unique bit string. This leads naturally to logarithms base 2, since the number of bits required to represent k objects is the integer above $\log_2(k)$. The base 2 representation of positive integers and base 2 arithmetic was introduced by Unifix cubes [6] in a hands-on activity, and then was done arithmetically using the division algorithm. While doing each step arithmetically, we referenced the corresponding step in the activity with the Unifix cubes. This shows the correspondence between the division algorithm and the grouping of the Unifix cubes into blocks. We only showed how to represent positive integers using bits in 1998. In 1999 and 2000, we also showed the representation of negative integers using the twos complement system. It is worth noting that representations of rational numbers and scientific notation could be inserted at this point.

After these basics, we began with Digital Logic Labs 1 through 6. Lab 1 dealt purely with the proper way to wire LEDs and how the breadboard was used. In Digital Logic Lab 2, the students investigated the six types of logic gates contained on the ICs and constructed input/output tables for each. After this assignment, we gave them the names and commonly used symbols for the logic gates. Labs 3 and 4 and the subsequent homework were designed to help the students understand the proper way to connect gates. The students also began wiring and testing circuits involving multiple logic gates. We stressed the relationship between the actual circuits, the circuit diagrams, verbal descriptions of the circuits, and the input/output tables. We repeatedly asked the students to describe circuits in all four ways. One example, which we frequently used was the "majority vote circuit" which had an output of 1 if and only if a majority of the inputs were 1. At this point, the students were ready for more complicated projects.

Before Lab 5, Boolean expressions representing circuits [7] were introduced. This gave the students an algebraic language to describe and manipulate circuits. In Digital Logic Lab 5, the students discovered that two different circuits can have the same input/output table. We defined the corresponding Boolean expressions as logically equivalent. This notion of logical equivalence gave the students a mathematical way to show that two circuits do the same thing. Lab 5 is reproduced in Appendix A to give you an idea of the structure of these labs. We stressed this concept as a way to reduce the number of gates used in a circuit.

The students had been asking how to design a circuit to do a particular task. Previously, we had refrained from telling them much about this, but now we spent some time on this topic. Digital Logic Lab 6 led the students to discover the Disjunctive Normal Form (DNF) [8], and we then talked at length about this and some other ways of designing circuits. We also talked about simplifying circuits using Boolean algebra [9]. We found that working with the circuit boards was very helpful to the students' learning. This helped make the techniques and concepts much more "real" to the students. Some students found that, while at first they did not understand the circuit's function, hands-on experience wiring and testing the circuit helped them understand the circuit. As one of the students commented: "We were able to watch as our ideas were put into motion."

We introduced the theory of error correcting codes using Coding Lab 1 which is reproduced in Appendix B. The students constructed by trial and error a 5-bit code with four valid code words, which would correct one error. The idea we wanted them to discover was that any two code words must differ in three positions if the code is to be able to correct one error [7]. As the students worked on Coding Lab 1, we went around the room and looked at their attempts, pointing out where each of their attempts failed. If any two code words differed in only one position, then we can convert the code word to another valid code word by changing one bit. Since both words are valid, the students can't detect the change. Thus, their code would not detect or correct this one error. If any two code words differed in two positions, we would change the bit in one of those positions. The students found that they could not determine the proper message and therefore could not correct this error. Thus, they were led to the conclusion that in a code, which corrects one error, each code word must differ in three bits from any other code word. Most of the teams got an answer on their own and with a little help by the end of the period, they all did. This lab formed the basis of most of our discussions about coding.

The ball of radius one around a fixed code word (called the center of the ball) is defined as all words that differ in only one bit from that code word. From Coding Lab 1, the students discovered the fact that a code, which can correct one error, must have disjoint balls of radius one. Therefore, the centers of the balls must be sufficiently far apart. The Hamming distance between two words is defined as the number of bits where the two words differ [7]. The students were asked to fill in a table of the distances between code words in each of the codes that they developed in Coding Lab 1. The students observed that the minimum distance between valid code words was three and that this was necessary in a code which would correct one error.

The students learned that the Hamming distance function d satisfies three important properties. These properties make error detection and correction possible. These properties are:

(1) $d(x,y) \geq 0$ and $d(x,y) = 0$ if and only if $x = y$

(2) $d(x,y) = d(y,x)$

(3) $d(x,y) \leq d(x,z) + d(z,y)$

for all bit strings x, y, and z. We proceeded to define a metric [10] as any function that satisfies these three properties. We showed how these abstract properties allowed errors to be detected and corrected. The distance function between points in a Euclidean plane is another example of a metric. The students were asked to find other examples of metrics and write a small paper on them.

The discussion ended with a result called the *Sphere Packing Limit*, which relates the minimum Hamming distance between code words to the power of a code to detect and correct errors [11]. It states that if n is the number of bits in each code word, M is the number of valid code words and t is the number of errors we want to correct: $M\cdot\left[\binom{n}{0}+\binom{n}{1}+\cdots+\binom{n}{t}\right] \leq 2^n$. We mentioned that a code is *perfect* if equality holds above.

The students had come up with a number of 5-digit codes from Coding Lab 1 and we wanted to know how many such codes there were. First, we wanted to see how many new codes we could construct from the codes that they found by trial and error. The students were shown the idea of a "FLIP," where the bits in a particular position on all of the valid code words are flipped from 0 to 1 or vice versa, and of a "SWITCH," where the bits in two different positions are interchanged in all code words. We defined a specific five-digit code, called the standard code, which could correct one error. Its code words are 00000, 11100, 00111, 11011. We had the students convert the standard code to one with a specific word in it by using FLIPS and SWITCHES, recording their steps.

Next, they were asked to complete a distance table for their new code. They observed that this table was the same as the one for the standard code and concluded that FLIPS and SWITCHES preserve distances. We defined an isometry [10] as any operation that preserves distances. They were assigned some homework on this topic to make sure that they understood the ideas discussed. Every team converted their code to the standard code by FLIPS and SWITCHES and presented their results on the board.

Finally, we proved that every five-digit code with four code words, which can correct one error, is equivalent under an isometry to the standard code. We were extremely interested in the journal entries for this class. All of the students claimed to understand the procedure for converting to the standard code and most actually demonstrated their knowledge. Some of the students were clearly impatient with the detailed argument and did not understand why we needed such an argument. However, they were all able to see why the argument implied that there was no five-digit code with five code words that can correct one error.

Next, we mentioned that isometry of codes is an example of the more general concept of an equivalence relation. In 1999 and 2000, the instructors spent more time on equivalence relations and had the students write a paper on other examples of equivalence relations. Most students noticed that equivalence of circuits was another example of an equivalence relation.

At this point, we introduced the 7-bit Hamming code (which is a perfect code). The position of errors in this code can be found easily by using Venn Diagrams [7] or by using modular arithmetic. In the Spring 2000 class, we discussed an efficient method for finding errors in this code using matrix multiplication. In the last part of the coding theory section, we explored bar codes [12]. There are, of course, a number of good references concerning coding theory [13-16].

The hands-on circuit designing experience and the mathematics were interwoven throughout the course, especially in the final project. The purpose of the final project was to design and implement a large circuit that accomplishes some task involving coding. The students worked in groups of two or three. Before starting on the actual wiring, they designed their circuit on paper. Then, they checked their design carefully to see that it accomplished the required task with a reasonably small number of chips. Each group implemented a different project from a list of final projects reproduced in Appendix C.

Summary of Educational Objectives

The course had the following major educational objectives:

- To introduce the students to some high-level mathematical ideas and notations

  We helped the students to understand how to approach complex mathematical problems by using abstract mathematical ideas. For example, logarithms were used to relate the number of possible bit strings of fixed length to the number of bits in one of them. Given a set of objects, the number of bits required to associate a distinct bit string to each object could be calculated. Another example is the use of the concept of divisibility to analyze bar codes. The students saw how mathematical notations were developed and observed that many of the decisions that went into their development are arbitrary [17]. In several places, the students were asked to develop their own notation, and after they had done so they were given the standard notation. We then spent some time looking at what made a notation good. One student cited the importance of "the relationships between notations and concepts."

- To teach the students to generalize from an example to an abstract concept

  In problem solving, abstraction often helps to get at the heart of the problem. For example, the students found that it was much easier to use circuit diagrams with symbols for logic gates rather than wiring diagrams because the former were not cluttered with the resistors and LEDs, necessary to the wiring, but not to the design of the circuit. Boolean expressions represented an additional level of abstraction. They helped greatly when designing a more efficient circuit, one that used a smaller number of logic gates.

- To help the students become more effective problem solvers

  Some student comments illustrate this point effectively.

  "...to attack a problem from different angles.."

  "The kind of problem solving we were doing was very different from any other I have done. I think my ability as a problem solver was expanded due to this."

  "... going from a global point of view and moving down the ladder to small steps."

"... first understand what the problem is or what exactly it is asking ... examing [sic] relationships between things and look for patterns. I feel more confident about solving problems, because I have solved harder problems than I have ever had to solve before."

- To teach the students to break complex problems down into simpler pieces

  Once the problem was decomposed into simpler pieces, the students found it easier to solve these individual pieces and could then integrate their solution of them into a solution of the original problem. One student told us that, "this makes solving any problem, no matter the level of difficulty, a possibility. I never looked at problem solving like this before." The final project, because of its complexity, required the students to apply this approach extensively.
- To help the students become more comfortable with technology

  We found that most of these students were either poorly informed about technological issues or were afraid of dealing with them. For example, they found wiring the circuit boards intimidating at first. Once they developed good techniques, they became much more comfortable and even enjoyed wiring circuit boards.

Student Reflections as Given in the Journals

The journal entries submitted gave the students an opportunity to reflect on what they learned. Since this course is part of a teacher preparation program, it was interesting to see that several of the students found that their own learning process was helpful in this context.

"In order to truly identify with our students, we have to remember how it feels to deal with abstract concepts and search for understanding."

"This course is designed for us to think in the way we will one day want our students to think and be curious about mathematics."

"If we do this kind of mental role-playing, then we will better understand our students and become better teachers for it."

Many students felt that the amount of time spent doing hands-on activities was a valuable part of their experience.

"It is amazing what a little hands-on learning can do to the understanding of a topic. If we had just talked about circuits and discussed what happened when we used resistors, LEDs, and wires, I think I would have been totally confused. But when I was able to play around with the switches and circuits, I gained a better and more complete understanding ..."

"Sandi and I had a little 'accident' when we wired the cathode of the LED directly to the ground with a 270 ohm resistor. This is the best way for me to understand exactly what a resistor does."

"...I can't tell you how happy I am that we're finally going back to working with the circuits. ...I missed the hands-on aspect of working on the digital logic labs."

Several students observed that the process of explaining ideas to others was very helpful to their own learning.

"...I was eager to share my understanding of that material with others. I hope that when I am a teacher I can inspire this kind of enthusiasm in my students, and I think one of the best ways to do this is by displaying enthusiasm for the subject matter myself."

"...I explained how to do some of the problems to another person. This cemented in my mind exactly what I would have to do to solve a problem, and it allowed me to make sure that the way I was explaining the information was clear and concise."

"I am anxious to explain our findings to Lisa what she returns on Tuesday, seeing if I actually can explain what I have done, proving that I understand what I'm doing."

The journals showed that during the semester, the students improved significantly in their ability to deal with the course material.

Analysis of Student Responses on the Assessment Form

The students were assessed on their knowledge of the course content on the exams and projects. The effectiveness of the course in achieving its educational goals was evaluated at the end of the course using a course assessment form. They were given 10% of their grade on the final exam for completing this assessment. The results were analyzed only after all final grades had been turned in. The assessment tool we used is reproduced as Figure 4.

Figure 4

MATH/COSC 326 Assessment

Directions: Please circle the number which best describes your perception of this course and then write a paragraph about your experiences. This assessment is to be turned in to Dr. Lorie Molitor and you will get 10 points on the Final Exam for turning it in.

1. How effective has this course been in giving you experience in breaking a problem down into simpler pieces?

Very effective			Not effective at all	
5	4	3	2	1

Paragraph: Give an example from this course where you broke a problem into simpler pieces and solved each piece.

2. How effective has this course been in giving you experience in generalizing from an example to an abstract concept?

Very effective			Not effective at all	
5	4	3	2	1

Paragraph: Give an example from this course where you developed a general concept from looking at concrete examples.

3. How well did the topics in this course fit together? Was there a central theme or themes?

Very well				Not well at all
5	4	3	2	1

Paragraph: What was the main theme or themes of this course?

4. How well has this course given you experience in being a flexible problem solver?

Very well				Not well at all
5	4	3	2	1

Paragraph: Give an example of a problem that you solved that you are particularly proud of and explain why you are proud of your solution.

5. Has this course given you any new understanding of abstract mathematical concepts that you did not have before the course?

Yes, a lot.	Yes, some.	None
5	3	1

Paragraph: Give an example of a mathematical concept that you feel you understand well that you did not understand before this course. It does not have to be a major concept.

6. Has this course given you any new understanding of how notations are developed to represent concepts and objects?

Yes, a lot.	Yes, some.	None
5	3	1

Paragraph: Give an example of a notation that you feel you understand well and discuss its strengths as a notation.

7. How effective has this course been in helping you to feel more comfortable with technology?
Very effective Not effective at all
5 4 3 2 1

8. How effective has this course been in helping you to feel more comfortable with abstract thinking?
Very effective Not effective at all
5 4 3 2 1

9. How effective has this course been in helping you to feel more comfortable with mathematics?
Very effective Not effective at all
5 4 3 2 1

10. How well did this course embody the MCTP philosophy?
Very well Not well at all
5 4 3 2 1

11. How well did this course fit in with the other MCTP courses that you have taken?
Very well Not well at all
5 4 3 2 1

12. How has this course impacted your approach to problem solving?

The responses of the three classes on the assessment questions were surprisingly uniform. A hypothesis test using an alternative hypothesis that the means were different in pairs for the three classes for each question yielded little support for this hypothesis, except for question #3. In question #3, it was observed that the 1999 class had a significantly lower mean than either the 1998 or the 2000 class. A comparison of the 1999 and the 2000 class with the null hypothesis that the means were equal yields a p-value of $p = .0056$ and the same comparison between the 1998 class and the 1999 class gives a p value of $p = .055$. Since this question asked whether the course had a central theme, we can conclude that the 1999 class did not see the organizing theme as well as the other classes. Nevertheless, we note that the 1999 class had a mean response to this question of 3.47 on a 5-point scale and the authors consider this a good response. The means for the 1998 and 2000 classes were 4.21 and 4.57, respectively. Therefore, we feel comfortable in pooling the data from the three classes for all questions. A bar graph illustrating the numerical results of the assessment on all questions for each of our three *Math 326* classes is included as Appendix D.

The results of this pooled analysis are given in Table 1. There were 34 students in the three classes who filled out assessments and *N* is the number of these students that answered any particular question. We would also like to point out that the 1999 class contained an unhappy student who did not see why this material was needed for teaching in elementary school. This student gave scores of 1 (with 5 being the highest) on 9 out of the 11 questions. Statistically, these responses can be considered outliers on 5 of the 11 questions. After careful deliberation, we decided to include this student's responses on all questions. However, we would like to note that this depresses the mean by .08 on average and significantly increases the standard deviation.

The results of the assessment may be summarized as follows. On question #1, the students felt strongly that the course was effective in giving them experience in breaking a problem down into simpler pieces. As an example of this, many students cited their final project and how wiring circuits forced them to break problems into simpler pieces. Two of the more interesting student responses follow.

> "There are so many examples. One is the majority vote circuit and how we went from the concept to the actual gates and wires. The whole class was breaking down concepts into simplified pieces. Isn't that a large part of 'math' also? We did a lot of 'math.' The class built the idea of a circuit, broke it down into pieces, and then went as far as explaining how to fix the pieces when a mistake is made."

> "In March we learned to use DNF [Disjunctive Normal Form] to create a circuit diagram for a table that has more than one 1 on it. We used DNF to create a table for each of the 1's, then we created a circuit for each of these tables. Then to join each of the circuits, we added an OR gate between them."

On question #2, the students felt that the course was effective in giving them experience in generalizing from an example to an abstract concept. Here the students' examples covered virtually every topic in the class. Here are several representative student comments.

> "We used abstract concepts when we discussed the triangle inequality."

> "The Hamming Distance. By looking at a few tables and example codes I was better able to understand the concept."

> "We began learned [sic] about logic gates by using a breadboard to see the inputs and outputs of the actual chips. Then we continued to move towards the abstract concepts and ideas of representing these chips with Boolean algebra and

diagrams."

"For example, in Coding Lab 1 we had to find a 5-bit code where an error could be detected. We were later told a way to make finding one easier: a code can correct up to *r* errors .... (2r+1) units apart."

"When we discussed a formula for combinations, it was after we did examples and realized that it was a lot of work to do by working out each combination."

"When we learned the twos complement, we used examples. We then made it abstract by using variables to represent a positive number and the negative of that (in binary). We showed how they when added together will come out to zero." (This student included an extensive diagram of the whole process.)

Question #3 asked the students to identify the central theme of the course. Most of the students saw the dual themes of "wiring" and "coding" and usually considered one of them to be subordinate to the other one. Some student comments illustrating this viewpoint follow.

"Everything in the class eventually focused on two major topics: coding & circuit diagrams (wiring). At one point, we started working with logarithms and all of us thought that this was useless, but it turned out that this helped us to figure out shortcuts when we were working with binary numbers."

"I felt like the main theme of the course was built around computer systems (bit strings, logic gates, and circuit boards). However, with all this, we had to implement many mathematical concepts. We used permutations, combinations, logs, probability, Boolean expressions and many other math concepts."

"The main themes of this course were (1) Exploration of higher level mathematical ideas (2) Intro into circuits and circuit design/execution. These main themes did go together very well though and in fact were interwoven throughout the course."

Other students answered this question by commenting on the educational objectives of this course and how they felt about them.

"I think that one of the main themes of this course focused on changing the way that we think. We were often influenced to think about things abstractly or mathematically. A lot of this course had to do with mathematics."

"I felt too much of an emphasis was put on topics such as logs and metrics. It seems like the course tried too hard to incorporate higher level math."

Question #4 asked if the course encouraged the students to be flexible problem solvers. Most students thought the course succeeded with this task. The students were asked to give an example of a problem that they solved that they were particularly proud of. With a few exceptions, the final project was the example mentioned. The difficulty of the project and the level of teamwork needed to solve it were repeatedly cited. Some of the student comments were:

> "The final project gave me the perfect opportunity to tie all of my understandings together. Constructing that circuit was something I never would have comprehended before, but now I could do it, understand it, and explain it pretty well. It served nicely as a culminating activity."
>
> "The final project of solving a circuit setup that has specific inputs, the output would indicate the number of one's that were in the input. I am proud of the solution to this, because I wouldn't have even understood what this problem was asking at the beginning of the class. Now I could figure out what I needed to hook the circuit up. Finally, when we went to wire the circuit, we were able to do so on the 1st try."
>
> "We had to simplify the majority vote circuit down to five gates! This required logical understanding of the problem, not just how gates work."
>
> "... I had to work harder on not getting discouraged and frustrated than on being flexible in solving a problem. ..."

Question #5 asked the students if they achieved any new understanding of abstract mathematical concepts. The results reflected some new understanding, but the standard deviation was quite high. Most students cited an improved understanding of number systems, logarithms, combinations or modular arithmetic although other topics such as metrics were also cited. Our hope was to introduce some sophisticated mathematical concepts to the students. Some students achieved a deeper understanding of these ideas than others, but the journal entries showed that all of the students had some ability to abstract ideas from the labs and projects.

> "If someone had said 'parity' to me three months ago, I would have had no idea what they were talking about. I would not have understood check bits or bit sequences. While these are more computer concepts that are related to mathematical concepts, I believe my understanding of base 2 counting in general has developed too. There are just so many things that were new to me before this course, that now I understand (or at least can recognize)."
>
> "I could never grasp the concept of logarithms before this class. The way it was

explained was very helpful."

"Once again, Permutations and Combinations. Not one math teacher that I have ever had explained the difference. There was Permut. And Combin., with no comparison of the two. Even though our professors touched briefly on this topic, I gained a lot by asking the question, "What is the difference ...?""

Question #6 concerned the student's understanding of how notations are developed to talk about abstract objects. We spent more time on notations as abstract entities in the 1998 class than in the 1999 and 2000 classes where we merely pointed out the advantages of particular notations. Since four students in the 1998 class said that they did not understand the question, we chose to de-emphasize this part of the course. Most student responses in the 1999 and 2000 classes were to give a specific example of where a notation (usually Boolean Algebra) made life simpler. Here is one of our better students from the 1998 class:

"Symbols that represent gates. I didn't see this as a strong point of the course. I already understood that notations can be very arbitrary and ofter [sic] has no real logic for designating "D" as an and gate versus "?" or "?". It was mentioned throughout the course how arbitrary notations can be, and I think more emphasis should be placed on this idea. This idea can extend to all mathematical symbols as 'man-made.'"

Here is a representative student comment from the 1999 and 2000 classes:

"Boolean expressions are a notation form that I understood well. By going from a table or circuit diagram to a Boolean expression, you can determine how to verbally describe your circuit. The strength of the notation was that it made sense, and paralleled the diagram and the circuit table that was constructed. Overall, it proved an easy way of describing the circuit."

On the next three questions, the students responded that the course was moderately effective in making them feel more comfortable with technology, abstract thinking, and mathematics. The students felt strongly that this course embodied the MCTP philosophy, but that it was only somewhat related to the other MCTP courses that are taught at Towson University. The instructors believe that the uniqueness of the course content obscured the relationship with the other MCTP courses at Towson.

Finally, we asked how this course impacted the student's approach to problem solving. The overwhelming response was that this course taught them to break a problem down into smaller, more manageable pieces, solve those pieces, and then assemble the solutions into a solution of the whole. The process of designing a circuit with a particular output encourages this problem solving strategy.

> "I look for the big picture first and then break the problem down into pieces. Looking for the overall goal or outcome and sketching a draft plan to reach that goal and then break it down further into steps. I liked going from a global point of view and moving down the ladder to small steps."

> "I thought I had a good grasp at breaking down problems, until this class! The relationships between notations and concepts is clearer. I have become more confident in being able to see them. Therefore I guess the class was a good thing..ha ha..the class was great. I am glad I took it."

> "This course has taught me that I must first understand what the problem is or what exactly it is asking. This course has also really showed me how to examine relationships between things and how to look for patterns. ... I feel more confident about solving problems, because I have solved harder problems than I have ever had to solve before."

> "If there is one thing I have learned from this class, it's that there is always more than one way to approach and solve a problem."

> "The nature of the subject forces me to examine each step of the process. My difficulties with problem solving resided in trying to reach a conclusion without thorough understanding of the process. In analyzing circuit diagrams and input/output tables, as well as Boolean expressions, I learned how to more effectively work through the processes of examining each step. This course essentially exercised my ability to solve problems carefully and logically."

Conclusion

The instructors view the specific content chosen as an excellent vehicle for achieving the educational objectives of the course. The richness of this content allows many mathematical ideas to be explored. In addition, the content was accessible to the students. They were able to learn the course material and performed well on the examinations. The students' final projects were exceptionally well done and demonstrated mastery of the course content. As with any inquiry-based method of learning, the students experienced fairly high levels of frustration. This frustration was kept manageable by having the students work in teams and by the instructors periodically checking the progress of each team. Thus the content and pedagogical approach were well suited to achieve the educational objectives.

We achieved more success with some of our educational objectives than with others. We felt that this course was extremely successful in helping students to become more effective problem solvers and in encouraging the students to break problems into smaller and more manageable pieces. Wiring actual circuits helped the students become less afraid of technology. After their experiences in this course, they felt more confident that they could handle unfamiliar technology.

We were moderately successful in helping the students become more comfortable with high level mathematics and in improving their ability to generalize from examples. One very positive benefit that occurred repeatedly was the "now I understand that" experience. Much of the students' previous mathematical knowledge was applied to new and "real-life" situations. This required them to understand the mathematics that they were using, instead of merely being able to compute the answer to a standard test question. One student even mentioned that this was true for the topic of "subsets." This is particularly amazing since we spent at most ten minutes on a whim asking the students how a computer might represent a subset of a set.

Although this class was designed for the MCTP program, the subject is accessible to the average college student. With minor modifications, this course would make a good general education course. The subject matter is rich enough to use diverse mathematical ideas and to provide many opportunities for hands-on learning. Introducing elements of computer hardware made the students more comfortable with computer technology. We are quite excited about *The Mathematics of Information Science* and look forward to teaching it again. ■

Acknowledgments

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Table 1 - Assessment Results

Question	N	Mean	σ	Precision
1	34	4.12	.80	±.27
2	33	3.77	.79	±.27
3	34	3.96	.99	±.34
4	34	4.09	.74	±.25
5	34	3.88	1.21	±.41
6	29	3.55	.89	±.33
7	34	3.91	.92	±.31
8	34	4.00	.91	±.31
9	34	3.65	.97	±.33
10	34	4.21	.83	±.28
11	33	3.23	1.11	±.38

Appendix A

DIGITAL LOGIC LAB 5

Purpose: To learn to develop a circuit diagram starting from a Boolean expression for the circuit. To develop a method for testing to see whether or not two circuits are equivalent. To implement this method by actually wiring some circuits.

1. For each of the following Boolean expressions, give a circuit diagram which implements the expression.

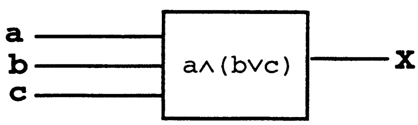
(a) $a \wedge (b \vee c)$

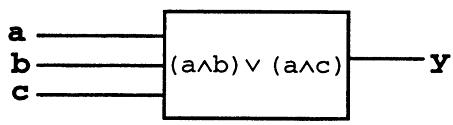
(b) $(a \wedge b) \vee (a \wedge c)$

2. Use input/output tables to determine whether or not these circuits are equivalent.

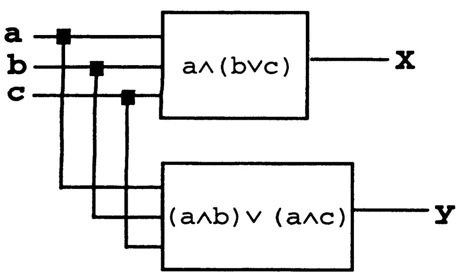
3. Wire the circuit $a \wedge (b \vee c)$ (from 1(a) above).

4. Suppose we use the following block diagrams to represent the circuits $a \wedge (b \vee c)$ and $a \wedge (b \vee c)$:

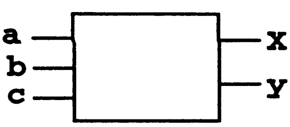




Wire the $(a \wedge b) \vee (a \wedge c)$ circuit (from (b) above) on the same breadboard on which you already constructed the circuit $a \wedge (b \vee c)$ by using the following scheme which will make it easy for you to compare the two circuits.



Note that the block diagram for your entire circuit is



which is the first two-output circuit you have wired!

5. Demonstrate this circuit to your instructor explaining whether it shows that the two circuits a ∧ (b ∨ c) and (a ∧ b) ∨ (a ∧ c) are equivalent or not equivalent.

6. Since the 74LS08 and the 74LS32 chips have exactly the same pinouts, you can just swap the 74LS08 and the 74LS32 chips in the circuit above to check to see whether or not the circuit a ∨ (b ∧ c) is equivalent to the circuit (a ∨ b) ∧ (a ∨ c).

7. Before testing to see if these new circuits are equivalent, predict the answer using circuit tables.

8. Demonstrate this new circuit to your instructor explaining whether it shows that the two circuits a ∨ (b ∧ c) and (a ∨ b) ∧ (a ∨ c) are equivalent or not equivalent.

9. Are either of the circuits of #8 the same as either of the circuits of #5? Explain your answer.

Appendix B

Coding Lab 1

Purpose: To introduce the principles of error correcting codes.

Step 1: Construct two 3-bit sequences. The first sequence will represent the word "ONE" and the second will represent the word "TWO". You agree on this code with your lab partner.

Questions:

You write one of these code words on a piece of paper. As you are about to give this paper to your partner, Dr. Zimmerman sneaks over and might or might not change one bit on your piece of paper.

1. Can you tell if he has made a change or not?

2. Suppose that you know that he has made a change. Can you tell what the correct message is?

Step 2: Try this out first with your partner and then with Dr. Zimmerman or Mr. Smith. If you cannot answer both questions above with a YES, then start over on Step 1 and redesign your code.

Step 3: Explain why your code works. If you cannot do this, find a code, which doesn't work and explain why it fails to work.

Step 4: Construct a 5-bit code, which will encode four items, "apples", "bananas", "cherries" and "oranges". Design your code so that you can detect if one bit has been changed and correct it.

Step 5: Try this out first with your partner and then with Dr. Zimmerman or Mr. Smith. If you cannot answer both questions above with a YES, then start over on Step 3 and redesign your code.

Step 6: Explain why your code works. If you cannot do this, find a code which doesn't work and explain why it fails to work.

Hand in both codes that you came up with and your explanation of why it works.

Appendix C

Final Projects

1. A Hamming encoding circuit. The 4 input bits give the message to be sent and the 7 bits of the output give the valid Hamming code for this 4-bit message.

2. Part 1 of a Hamming decoder. This project has 7 input bits and 3 output bits. The 7 input bits give the received Hamming code of a message. This could be the valid code word for a message or it may differ from some valid code word by one bit. The 3 output bits give the binary form of the subscript of the error bit if there is an error or are all 0 if there is no error. For example, if there is an error in a_5, the 3 output bits are 101.

3. Part 2 of a Hamming decoder. This project has 7 input bits and 4 output bits. Three of the input bits are the 3 error location bits generated by Part 1 above. The remaining 4 input bits are the 4 uncorrected message bits of the received message from Part 1. The project generates as its 4 output bits the correct message.

Note: Part 1 and part 2 above when wired together form a complete Hamming decoder.

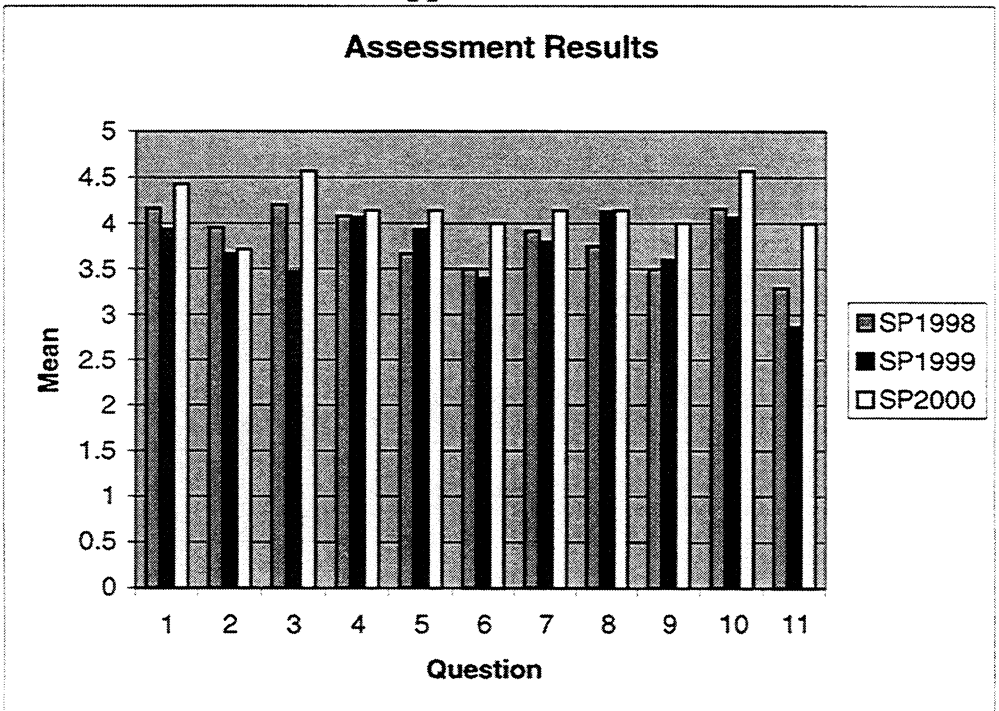
4. A 2-bit adder. This project has 4 input bits and 3 output bits. The 4 input bits are grouped into 2 pairs with 2 bits in each pair. Each of these pairs represents a 2-bit binary number and the 3 output bits represent the sum of these two numbers. For example, if one of the input pairs in 10 and the other input pair is 11, the output bits are 101 (since 2 + 3 = 5).

5. A 1-bit arithmetic logic unit (ALU). This project has 3 input bits a, b and s and 1 output bit x. If s is 0 then the output bit x is $a \wedge b$ and if s is 1 the output bit x is $a \vee b$.

6. A 3 bit 1's counter. This project has 3 input bits and 2 output bits. The output bits display in binary form the number of the input bits that are 1. For example, if the input bits are 101, the output bits are 10.

7. A Hamming distance evaluator. This project has 6 input bits and 2 output bits. The input bits are grouped into 2 pairs of 3 bits each. The output bits give in binary form the Hamming distance between the two pairs of input bits. For example, if one input pair is 011 and the other input pair is 110, the output bits are 10 since the Hamming distance between 011 and 110 is 2.

Appendix D


Assessment Results
Mean
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
Question
SP1998
SP1999
SP2000

SHAPING PRE-SERVICE TEACHERS' ATTITUDES: AN INQUIRY APPROACH TO COURSE REFORM

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The purpose of the study was to investigate the development of pre-service teachers' attitudes toward teaching science with inquiry methods as the result of their participation in the two-hour elementary science methods class. Southwestern Oklahoma State University is a partner in the Oklahoma Teacher Education Collaborative (OTEC) which is funded by the National Science Foundation's reform effort, Collaboratives for Excellence in Teacher Preparation (CETP). The reform effort focuses on the revision of the teacher preparation courses with emphasis on a systemic change in the method in which math, science, and education methods courses are taught across Oklahoma.

Nine Oklahoma universities, including the University of Tulsa, Oklahoma State University, the University of Central Oklahoma, Northeastern Oklahoma State University, Cameron University, Langston University, Tulsa Community College and Southwestern Oklahoma State University, have focused on revising the identified courses with inquiry-based instruction.

The Science Methods Course: *Teaching Science in the Elementary School*

The elementary science methods course, *SCI 4352: Teaching Science in the Elementary School* offered at Southwestern Oklahoma State University, has been revised with an inquiry approach to teaching science since the inception of the OTEC reform initiative. Revision of the science methods course was guided by the principles in *Science for All Americans* [1], *Benchmarks for Scientific Literacy* [2], and the *National Science Education Standards* [4]. The methods course is a two-hour per week lecture/lab course with two semester hours of credit.

One objective of the science methods course is to help pre-service teachers develop an individual understanding of scientific literacy. Without a clear meaning of scientific literacy, the pre-service teachers will not be prepared to assist their future students with attaining that goal. The interpretation of scientific literacy for the pre-service teachers to acquire is that science literacy is a combination of facts, terminology, concepts, history, and philosophy that a person needs to understand the everyday world [3]. It is paramount that pre-service students understand

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that scientific literacy is not specialized knowledge of the experts, but more general and practical knowledge [6].

National Science Education Standards

The National Science Education Standards (NSES) [4] are interconnected with the practical and theoretical experiences provided in the methods course. With guidance from the assistant professors, chapter readings, inquiry-based activities, and interactive discussions of the Standards, the pre-service teachers began to formulate personal visions of science education. These activities assisted the students in understanding that the NSES, as essential elements, promote the learning and teaching of science as an inquiry process.

The Learning Cycle

The focus of teaching science as inquiry was the acquaintance with the learning cycle, the Five E Model [5]; i.e., engagement, exploration, explanation, elaboration, and evaluation. The learning cycle approach to teaching, compared to traditional approaches, promotes higher order thinking and problem solving. The learning cycle enables the pre-service teacher to be prepared to teach science as inquiry with students in kindergarten through sixth grade.

Scientific Attitudes

Science is based upon scientific values including integrity, diligence, curiosity, skepticism, and imagination. Scientists use curiosity when they question new theories. The science methods course provides pre-service teachers with strategies to direct curiosity in productive ways [2,4,6]. In addition, the course encourages pre-service teachers to be open to new ideas by emphasizing the importance of analyzing ideas contrary to their beliefs. In the scientific community, informed skepticism enables scientists to give new theories careful attention through a process of verification and refutation [2,4]. Experiences in the methods course help pre-service teachers perceive the social value of skepticism and the need for balance between skepticism and openness to new ideas [2,4,6].

The Survey

The assessment tool used to evaluate the pre-service teachers' attitudinal change and confidence levels of teaching science with inquiry methods was designed by the authors. The questionnaire included fourteen items, organized into three categories: Teaching Science as a

Process of Inquiry, Teaching Science in the Elementary School, and Hands-On/Laboratory Activities.

The Questionnaire for Pre-Service Teachers in the Science Methods Course

PART I.
TEACHING SCIENCE AS A PROCESS OF INQUIRY

1. Teaching science as a process of inquiry is contrary to the traditional way in which I was taught in public or private school.
2. The attitudes of successful scientists are characteristic to the scientific attitudes that successful teachers should model.
3. Open-ended questions asked during discussions promote divergent thinking and elicit diverse responses.
4. Increasing wait time has positive effects on the inquiry climate of the classroom.
5. Nonverbal reinforcement is more effective than repeated verbal praise after every student response.

PART II
TEACHING SCIENCE IN THE ELEMENTARY SCHOOL

1. I intend to use the Constructivist Learning Cycle often to teach science.
2. I can use the inquiry approach to teaching elementary science more easily.
3. The National Science Education Standards recommend that I teach inquiry-based science.
4. My plan to teach more hands-on/investigative science is valuable.
5. Principals of elementary schools think that I should teach science as a process of inquiry.

PART III
HANDS-ON / LABORATORY ACTIVITIES

1. My attitude toward teaching science in the elementary school is more positive.
2. Hands-on/laboratory investigations are important.
3. Working in collaborative groups during investigations encourages student-student interaction.

4. Using the stages of exploration, concept introduction, and concept application promote meaningful learning.

Data Collected

Using the indicated student response scale, data collected with a pre- and post-questionnaire during the 1998 and 1999 semesters suggest that the pre-service teachers are developing positive attitudes toward teaching science with inquiry methods. These data represent a small number of elementary education majors; however, the two classes were taught by assistant professors using an identical syllabus during the spring and fall semesters.

5 4 3 2 1

5 = STRONGLY AGREE
4 = AGREE
3 = SOMEWHAT AGREE
2 = SLIGHTLY DISAGREE
1 = DISAGREE

PART I
STUDENT RESPONSES: TEACHING SCIENCE AS A PROCESS OF INQUIRY

QUESTION										
	5	**4**	**3**	**2**	**1**	N	**SET**	**MEAN**	**MED**	**SD**
1	6	7	**10**	4	1	28	PRE	3.5	4	1.1
	9	7	7	2	1	26	POST	3.8	4	1.1
2	7	**9**	6	4	2	28	PRE	3.5	4	1.2
	17	6	1	2	0	26	POST	4.5	5	0.9
3	**12**	10	2	2	2	28	PRE	4.0	4	1.2
	19	6	1	0	0	26	POST	4.7	5	0.5
4	6	7	**9**	5	1	28	PRE	3.4	3	1.1
	17	5	3	0	1	26	POST	4.4	5	1.0
5	4	3	3	**11**	7	28	PRE	2.5	2	1.4
	7	**10**	5	2	2	26	POST	3.7	4	1.2

Mode in Boldface.

PART II
STUDENT ATTITUDES: TEACHING SCIENCE IN THE ELEMENTARY SCHOOL

QUESTION										
	5	**4**	**3**	**2**	**1**	**N**	**SET**	**MEAN**	**MED**	**SD**
1	2	9	**17**	0	0	28	PRE	3.5	3	0.6
	11	**11**	4	0	0	26	POST	4.3	4	0.7
2	5	**12**	8	3	0	28	PRE	3.7	4	0.9
	17	4	3	2	0	26	POST	4.4	5	1.0
3	3	**12**	**12**	0	1	28	PRE	3.6	4	0.8
	15	8	3	0	0	26	POST	4.5	5	0.7
4	**17**	7	3	1	0	28	PRE	4.4	5	0.8
	22	3	1	0	0	26	POST	4.8	5	0.5
5	5	**13**	10	0	0	28	PRE	3.8	4	0.7
	9	**10**	7	0	0	26	POST	4.1	4	0.8

Mode in Boldface.

PART III
STUDENT RESPONSES: HANDS-ON / LABORATORY ACTIVITIES

QUESTION										
	5	**4**	**3**	**2**	**1**	**N**	**SET**	**MEAN**	**MED**	**SD**
1	10	**12**	5	1	0	28	PRE	4.1	4	0.8
	19	7	0	0	0	26	POST	4.7	5	0.5
2	**20**	7	0	0	1	28	PRE	4.6	5	0.8
	22	4	0	0	0	26	POST	4.8	5	0.4
3	**18**	9	0	0	1	28	PRE	4.5	5	0.8
	17	8	1	0	0	26	POST	4.6	5	0.6
4	11	**14**	3	0	0	28	PRE	4.3	4	0.7
	20	6	0	0	0	26	POST	4.8	5	0.4

Mode in Boldface.

Data Analysis

Using a standard deviation of ≥ +/- 0.2 as an indicator of significance [7], it is possible to see that changes occurred in our students from pre- to post-evaluation. Examining Part I, Student Responses Toward Teaching Science as a Process of Inquiry, three questions (#2, 3, 5) showed significant results. Question #2 addressed scientists' attitudes to that of successful science teachers (- 0.3). Question #3 addressed open-ended questions as promoting divergent thinking (- 0.7). Question #5 addressed nonverbal reinforcement as being more effective than verbal praise (- 0.2).

Part II, Student Attitudes Toward Teaching Science in the Elementary School, offered one question with significant change (#4). This question addressed the student's intention to teach science in a hands-on fashion (- 0.3).

Part III, Student Responses Toward Hands-On/Laboratory Activities, offered the greatest change with each question (#1, 2, 3, 4) being significant: question #1 addressed the student's attitude toward science as being more positive (- 0.3); question #2 addressed the importance of hands-on investigations (- 0.4); question #3 addressed the importance of working in collaborative groups (- 0.2); and, question #4 addressed the learning cycle stages as promoting meaningful learning (- 0.3).

Another indicator of significant change for data of these types is a change in mode [7]. Using an increase of two scoring categories as an indicator of significant change, several more questions can be analyzed. In Part I, questions #1(mode 3 to 5) and #4 (mode 2 to 4), and in Part II, questions #1(mode 3 to 4/5) and #3 (mode 3/4 to 5) showed significant change.

Conclusions

These data tend to indicate that a positive influence can be made with pre-service elementary educators with regard to science education. The importance of hands-on activities, the asking of open-ended questions, collaborative groups, and the learning cycle as being positive factors for good science education all showed a significant change from pre- to post-evaluation. Most importantly, the hands-on, participatory design of the science methods course (See Figure 1) provided the pre-service teachers with opportunities to develop the confidence needed to apply inquiry methods of teaching in their future classrooms.

Further research that examines the pre-service teachers' attitudes toward teaching science with inquiry method after they have completed one year of teaching, will be conducted. In Oklahoma, all beginning teachers are involved with a residency year program that includes university supervision and mentoring from teachers in the selected schools. These teachers will provide the cadre of participants for the follow-up study. ■

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THE IMPACT OF A SUMMER WORKSHOP: STAFF ORIENTATION AT MESA COMMUNITY COLLEGE

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The Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) is a National Science Foundation (NSF) funded project to reform teacher preparation in Arizona. One of the major modes for initiating both collaboration and reform between and among university and community college staff has been the Summer Faculty Enhancement Workshops developed and offered by ACEPT co-principal investigators each summer since 1996. The summer of 1999 featured five workshops, one of which was the *Geology Summer Workshop* which brought participants into close contact with eighteen reformed practices appropriate for large lecture style classes. One of the nineteen participants was Ray Grant, Department of Science Chair at Mesa Community College, one of the collaborating institutions in ACEPT. This report describes what Ray, as department chair, did as a follow-up to the summer workshop. What occurred completely transformed the Department of Science "staff orientation" meeting held just prior to the fall semester. Some of the surprising events are described in this report. The transformation of the staff meeting not only speaks to the impact of the *Geology Summer Workshop*, but also suggests creative roles for staff orientation meetings in community college settings.

"Saturday's meeting prompts this note. . . By virtue of many district policies, adjuncts usually feel like second class citizens. In my experience, no other department has made as much of an effort to lessen that impression as yours. . . I felt very good about being exposed to the same teaching improvement techniques as the full-time faculty. . . I got the feeling that improvement of my skills was deemed important. In short, that I was being treated like a professional."

Ann Slater, Adjunct Staff member
Mesa Community College
August 23, 1999

What Happened on Saturday?

Ray Grant, Chair of the Physical Science Department at Mesa Community College, usually has an orientation meeting welcoming full-time and adjunct instructors to the fall session. The Fall 1999 meeting was different. For the first time, it wasn't only about arranging for voice

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mail or handing out keys or dispensing coffee. It was different enough to prompt Ann Slater, an adjunct staff member, to pen the remarks quoted above. She wrote these remarks the following Monday, the first day of fall classes. What happened on Saturday to motivate such a response?

An ACEPT Summer Workshop

A few months earlier (May 1999), Ray Grant had participated in a Faculty Enhancement Workshop led by Dr. Stephen Reynolds, a member of the Geology Department at Arizona State University (ASU) and a Co-Principal Investigator of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT). It was one of many summer workshops offered by ACEPT as a major venue for sharing reformed pedagogy among college and university faculty. Dr. Reynold's *Geology Summer Workshop* had focused on eighteen reform-oriented instructional strategies and techniques, such as the learning cycle, concept maps, advanced organizers, analogies, think-pair-share, minute papers, jigsaw, cooperative learning, and multimedia — all suitable for use in the large lecture setting. Ray was convinced that sharing some of these methods with his staff would lead to better science teaching at Mesa Community College. The Saturday staff meeting would therefore be much more than a business meeting. Because of the intrinsic connection to the Geology Summer Workshop, Ray knew his plans for Saturday would be of interest to ACEPT personnel. He sent an open invitation to Sue Wyckoff, ACEPT Principal Investigator, welcoming any and all ACEPT personnel to the Saturday orientation at Mesa Community College. Two members of the ACEPT Evaluation Facilitation Group, Jeff Turley and Daiyo Sawada, accepted the invitation, arrived bright and early for the 8:30 a.m. meeting/workshop on Saturday August 21, 1999, picked up information packets, and enjoyed breakfast while relaxing with Mesa staff.

Déjà Vu

The meeting took place in a small lecture-style theatre (recall that the Geology Workshop had focused on pedagogical techniques appropriate for lecture-style classrooms) with seating for about 55 participants. The sloping tablet desks were arranged in five rows, each row elevated slightly above the row in front of it. At the front of the room was a long lab demonstration table. An RGB projector and a regular overhead projector were in front of it. Off to the side was a TV playback system on a cart.

The first part of the morning did indeed witness a business meeting. Welcomes were extended, announcements were made, information packets were distributed, and as Ray said in a joking manner, coffee was available in case anyone felt a powerful urge to sleep! Several business items, such as voice mail arrangements and accessing funds for supplemental support, were also discussed. After the mid-morning break, however, the agenda shifted. A brief video clip reminiscent of a classroom scene from *Ferris Buehler's Day Off* triggered several telling chuckles from attendees. The humorous portrayal of traditional teaching was a perfect backdrop for Ray and colleague John Zikopoulos to introduce the mission of the morning workshop. They did so by introducing the reform vision of ACEPT. Ray indicated that he appreciated the effort ACEPT had put into sharing reformed teaching practices and he hoped the morning's workshop would help everyone in carrying out their teaching responsibilities this fall. As an "advanced organizer," Ray distributed a two-page overview of the teaching techniques that would be the focus of the remainder of the day (see Appendix A). The first item on the handout was "Advanced Organizers" which was precisely what Ray was doing at the time! This "practice as you preach" or "model what you profess" attitude was characteristic of the rest of the workshop. It was also a major characteristic of the *Geology Summer Workshop* that Ray had attended earlier.

In addition to discussing items in the hand-out, participants engaged in two major, hands-on activities. The first was led by Jim Giles and embodied the learning cycle, and the second was guided by Ray with assistance from Donna Benson, a Department of Geology staff member at Mesa who also attended the Geology Summer Workshop. The activity was based on the module produced by Ray and Donna as part of that workshop. Both of these activities generated intense yet light-hearted discussion and critique.

Déjà Vu with Something New

Despite the obvious inspiration from and reliance upon the *Geology Summer Workshop*, what happened on this day was much more than a scaled down version. Not only were the instructional techniques tailored to the community college context, the techniques themselves were elaborated upon and used in creative ways. A good case in point was the learning cycle activity led by Jim Giles. The "burning candle in an inverted beaker" experiment, often used to illustrate the learning cycle, was part of Jim's activity. As described earlier, the workshop was held in a small lecture hall with five rows of sloped tablet desks, each with eleven desks per row. With more than fifty staff in attendance, the hall was more than crowded. To add to the confusion, Donna wheeled in about fifteen sets of beakers, candles, litmus paper, matches, water, etc. Working in small groups, participants were encouraged to select materials and equipment and carry out experiments to generate and test hypotheses. With so many people moving into action and with so little space of an appropriate sort to carry out the activities, things became more than a little problematic. Skeptical looks were exchanged between many of the participants. There were several nearby lab rooms which could have been used, but nothing was said about them. In this state of disorganization, Ray interrupted the proceedings for a special announcement. What Ray had to say caught many by surprise, but they understood his intent. "The activity itself is challenging enough, but I'm issuing you a special instructional challenge on top of that. Find a space in this lecture hall to do the experiment!"

Participants took on the challenge. The sloping tablet desks were useless because the experiment required a level surface for the water. Carts with AV equipment soon had no AV equipment on them. The platform steps leading from one tier to the next became lab tables. The demonstration lab table at the front of the room soon became the site of several experiments, as did the floor space around the demonstration table. It seemed that every square inch of level space was being put to good experimental use. It was impressive to see a lecture hall converted into a make-shift lab in about two minutes. No one complained about the space. All groups met the challenge. Many participants also felt the significance of what was happening. No longer would it be so easy to dismiss a hands-on activity in a lecture hall! Ray did NOT point this out. He didn't have to. It was there in the room; and the room was the message. His challenge triggered it; the participants enacted it. Again, Ray was *practicing without preaching*. The medium was the message; the message was the medium.

Readers familiar with the candle experiment will know that the activity revolves around generating alternate hypotheses about why the water rises in the inverted beaker as the candle burns. This activity never fails to generate heated discussion. After several sophisticated explanations were proposed and bantered about by the chemically erudite, one of the participants offered the final word concerning the rise in the water in the inverted beaker: "Hot air sucks!"

Déjà Vu Déjà Vu Déjà Vu

The Saturday Meeting/Workshop at Mesa Community College is a strong testament to the impact of the reforms initiated by the Geology Summer Workshop. The same could also be said about the Biology Summer Workshop where Jim Giles encountered the candle experiment. The continuing reverberation of the pedagogical effects of these workshops is bringing a new feeling of professionalism among adjunct instructors who often feel "out of the loop." Moreover, the summer workshop reforms were not merely being sustained; they were being sustained in creative ways. The Mesa Saturday workshop was not just the *Geology Summer Workshop* happening again. It embodied important elaborations not present in the original. With the Mesa Saturday Workshop in mind, it may not be unreasonable to suggest that, in the not too distant future, university staff may be attending state of the art summer workshops offered by community college staff.

During the luncheon break, the two ACEPT members attending as guests had the opportunity to chat with Ray and Donna. The conversation turned to the possibility of sustaining the momentum of the Saturday workshop through additional meetings where staff could share instructional experiences. Ray noted that holding such meetings on an ongoing basis would be a challenge because adjunct staff members are not regularly on campus. If the transformation of the lecture hall into a laboratory is any indication, Ray and his colleagues may have some further surprises up their sleeves. Meeting pedagogic challenges was the order of Saturday.

Later visits to Mesa Community College throughout the fall term indicated to ACEPT evaluators that, while not all participants took up the challenge of reforming their science classes, many expressed appreciation of the support available from the department chair's office. Details of evaluation studies carried out at Mesa Community College during that term are provided in ACEPT Technical Reports C99-1A and SW99-3 available from the authors. ■

Appendix A: Agenda for the Saturday Workshop

MCC ACEPT Workshop

Advanced Organizers

Day of Class:

- Outline of day's class
- Find out what students already know (at end of previous class or beginning of class)
- Activate students' prior knowledge (remind them what you did last class)

Entire Course:

- What-to-know list given at beginning of semester
- Early introduction of unifying concepts
- Post example test at end of first week (instead of right before test)

Classroom Activities

Learning Cycle Approach:

- Exploration phase
- Term and concept introduction phase
- Application phase

Ask questions (Minds-On learning-thinking about what is going on)

- Convergent questions for thinking about, not for answering out loud
- Divergent questions with student cooperation
- Wait time (minimum of 5 to 10 seconds; longer if divergent and very open-ended or complex)

Lecture Bursts (limit lectures to 10-15 minutes)
Consolidation Time (give students time to consolidate knowledge)
Do Sketches in Lecture
Think-Pair-Share

- Individually or jointly make observations/predictions/hypotheses
- Describe/explain to one another
- Make sketches and explain
- Compare and contrast; discuss similarities/differences

Minute Paper

- Short break to consolidate knowledge
- Compare with peers
- Can use for attendance and/or immediate feedback

Essay Questions
Even one on a test may make students study all the material differently because they know they may have to present coherent discussion about any topic.

Use Multimedia
- Observe/experience first
- Explain later (use learning cycle approach)

Journals
- Have students record key points of neatest thing they learned
- Write about how they felt about an activity

Memory Tricks
- Mnemonics
- Visualizing stories

Note: Some additional strategies for student learning

- Mix teaching techniques
- Have students actively solve meaningful problems together
- Ask for student feedback about reform effort – what worked today; what didn't work
- Have students reflect on and share connections to their own interests
- Minimize off-task time
- Use knowledge that is relevant and can be used again
- Do demonstrations; have students make predictions
- Emphasize learning and problem-solving or thinking skills
- Come prepared for class; choose what you lecture about carefully
- Use formal cooperative learning groups
- Content imbedded/required in problems

Students learn science best when

- They are actively engaged
- They are interacting with others
- They are solving problems
- The content is meaningful

STUDENT WORK SECTION

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Students in *Environmental Science* (one of the freshmen level courses included within the Virginia Collaborative for Excellence in Teacher Preparation program) are given the opportunity to socialize the material presented in large lectures by attending smaller guided recitation sections. In recitation, active learning is promoted through the use of role-playing, debates, and writing assignments. The following student paper is an example of such an assignment; it accounted for 2.5% of the course grade. The author is a freshman Pre-Nursing major who clearly demonstrated that she had integrated the concepts associated with acid deposition into the larger ecological picture and into her daily experiences. The work was supervised by Professor Bonnie Brown from the Department of Biology.

THE EFFECTS OF ACID DEPOSITION

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We are surrounded in a sea of gases. These gases in the atmosphere and certain chemicals mix with water to result in the deposition of a mixture of acidified compounds. Acid deposition is a global environmental threat. From lakes without fish to the ruin of human health, acid deposition has numerous harmful effects. Acid rain, sleet, snow, and other precipitants form when pollutants mix with droplets of water vapor in the atmosphere. The pollutants change the clean, fresh water to droplets of acid. Finally, these acids fall to Earth as various forms of acidic precipitation. However, rain is normally slightly acidic because of the carbon dioxide in air. Normal rain has a pH of 5.6. This is not considered to be a problem because natural systems are slightly buffered. Yet, when other anthropogenic gases are emitted into the atmosphere, then the precipitation becomes even more concentrated with hydrogen ions (acidic). This causes the pH to range from 3.4 to 4.5 [1]. Let's look at the numerous pollutants that cause acid rain and deposition.

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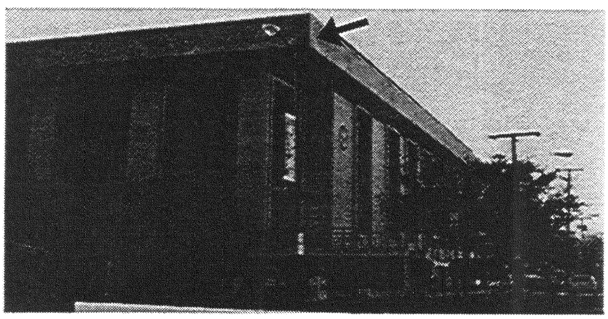
When fossil fuels such as oil, coal, and natural gas are burned, sulfur oxides and nitrogen oxides are emitted into the air. There, they mix with water droplets to make acids. Sulfuric acid accounts for 65% of the excess acidity in acid rain. Nitric acid makes about 30% of the remaining acidity portion in acid rain [1]. These oxides could be derived from factories, power plants, or industrial combustion processes. Ask yourself, "What do these have in common?" The answer is HUMANS! We are the main cause of acid deposition. The acid deposition is most severe in large cities due to the abundance of people and infrastructures that emit these harmful gases. The major cities of the U.S. and Canada have made the rain there ten times more acidic than normal. Also, the acid deposition affects areas that are far from the power plants and major cities because winds can carry pollutants great distances. The pollutants from the midwestern United States are regularly carried to New England and Canada [2]. This is why Canada frequently blames the U.S. for their acid deposition situation. Similar situations occur in Europe, South America, and Asia.

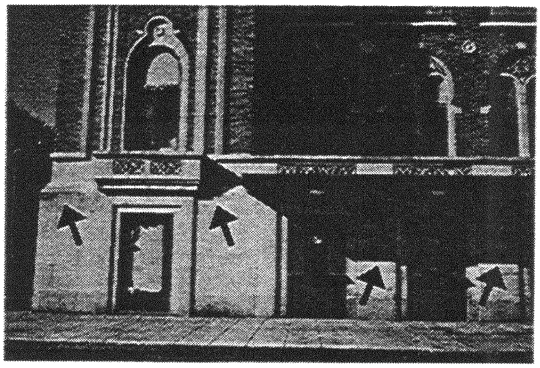
Let's look at the major effects of acid deposition. When acid rain falls to Earth, it soaks into the ground and causes the soil, plants, and rivers to become abnormally acidic. The acid materials deposited directly into the atmosphere alter the acid balance in bodies of water and reduce the pH level. Therefore, acids have a huge impact on plants. Aside from the unsightly spots on leaves and flowers, acids damage the protective wax and cellulose structures. The leaching of minerals from the soil depletes soil of the macronutrients (calcium, magnesium, and phosphate) necessary for plant germination and growth. Acid deposition interferes with photosynthesis. Acidified soil slows down the action of microorganisms needed to recycle nutrients. Acids increase the solubility of metals, eventually causing metal poisoning. Plants play a major role in removing toxins from the air, water, and soil. If the soil has a low pH, then plants will not be as effective in cleaning and stabilizing our environment. As another result of acid deposition, the aluminum and other metals in sediments and soil may dissolve in water and be absorbed by aquatic animals and plants. High levels of metals can kill the eggs of many fish and amphibians. In mature fish, gills can clog with mucous preventing efficient respiration. This disrupts the ecological equilibrium in the aquatic ecosystems. Young and small fish disappear, frogs disappear, mosquitoes flourish, and humans enter a positive feedback cycle of pesticide use and habitat destruction, ultimately resulting in further alterations of plant life. This affects local, native species and could even cause the extinction of a keystone species. Humans can be at risk from the effects of acid deposition. For instance, pollutants from acidic aerosols affect lung and respiratory activity. It also has been suggested that acid deposition can play a role in Alzheimer's disease [3]. To summarize, acid deposition can be harmful to plants, animals, humans, and even buildings.

Acid deposition affects the surfaces of buildings, bridges, automobiles, historical statues, and monuments. Limestone, marble, stone, concrete, and metals have been used throughout history for the construction of human infrastructures. Surface rock is destroyed when limestone or marble react with acid rain. Limestone reacts with nitric acid and sulfuric acid to form calcium nitrate and sulfate. Metal structures literally dissolve in acid. These chemicals, after a while, begin to erode and alter the surface and color of the anthropogenic structures, demolishing the structural components of buildings and ruining the aesthetic view of historical monuments. The damaging effects of acid deposition on structures can be seen near campus and around Richmond, Virginia (Figure 1). I was astounded at how much deterioration was occurring!

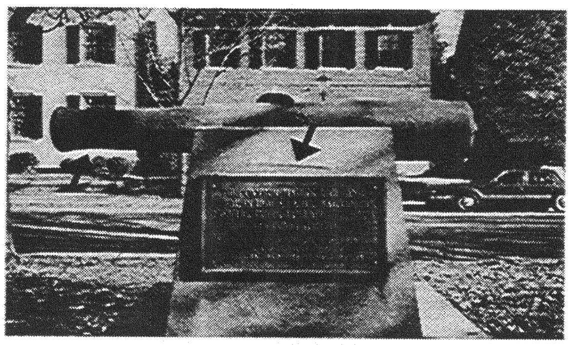
Figure 1. Well-known sites in Richmond, Virginia that show evidence of degradation (indicated by arrows) due to acid deposition.



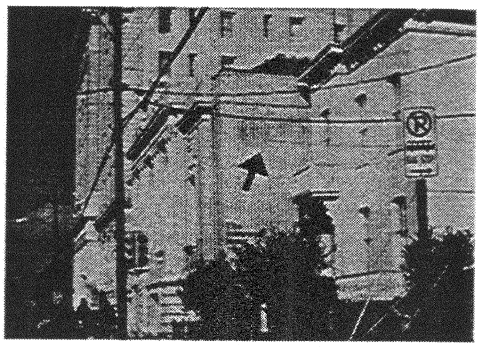
The Richmond (VA) Public Library shows evidence of erosion along the roof, (denoted by arrow) and discoloration of marble walls.



Extensive damage has occurred to Richmond (VA) Landmark Theater calcareous structural materials, particularly around doors and windows.



Typical monument in Richmond, VA showing erosion (pitting) and discoloration of concrete stand as well as accelerated rusting of the iron canon.



Acid deposition has marred the walls of the prestigious Jefferson Hotel in Richmond, VA.

How are we trying to prevent acid deposition? Some acid deposition cannot be prevented—volcanoes (sulfur oxides a.k.a., SO_x) and forest fires (nitrogen oxide, a.k.a. NO_x) for example. However, once deposited, some of the effects of acid can be remedied and much production of acid precursors is preventable. In the freshwaters of England and the U.S., acid precipitation is buffered by carbonates, so ecological destruction is slower to appear [3]. Once detected, reduced pH in a lake or pond can be increased by a technique called liming. Liming involves adding large quantities of hydrated lime to the waters to increase the pH. In 1990, the U.S. passed the Clean Air Act, which resulted in significant reduction of four of six major air pollutants by the year 2000. We have recently created electric vehicles that approximate zero emissions. Some sulfur compounds can be taken out of fossil fuel before it is burned. Yet, the best overall solution is to limit the emission of pollutants at their source. If each individual reduced their share of pollution by conserving energy and carpooling, then the acid deposition problem would decrease precipitously. ■

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AIMS & SCOPE

Articles are solicited that address aspects of the preparation of prospective teachers of mathematics and science in grades K-8. The Journal is a forum which focuses on the exchange of ideas, primarily among college and university faculty from mathematics, science, and education, while incorporating perspectives of elementary and secondary school teachers. The Journal is anonymously refereed, and appears twice a year.

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PART II: Regular Journal Features

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PART I: "Pathways to Change"

STEMTEC – Massachusetts Collaborative for Excellence in Teacher Preparation

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